A Study of the Relationships between Evoked Potentials, Inspection Time and Intelligence

by

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Declaration

This thesis is my own composition, and the work presented in it is my own.

To the lands where I grew up and where I am educated.

Abstract

This thesis examines the relationships between average evoked potentials (AEPs), inspection time (IT) and intelligence, by relating visual AEPs evoked by the stimuli of an inspection time task (and by similar stimuli for which an IT-type discrimination was not required) to subjects' IT estimates, and to their intellectual ability as measured by intelligence tests.

Earlier work on IT and AEP in relation to intelligence is reviewed.

Evoked potentials were collected while subjects were performing an IT (or an equivalent) task. In Experiments 1 & 2, it was found that a measure of the P200 ("$\mathrm{P200_T}$", defined in Chapters 3 and 4) of AEPs to the IT task stimuli correlated significantly with IT (Pearson: $r=0.57$, $p<.05$). Experiment 3 replicated this finding ($r=.44$, $p<.05$). Also, Experiment 3 found that P200 latency could be related to IT ($r=.55$, $p<.05$). These results were obtained again in Experiment 6 ($r=.645$, $p<.0005$, for $\mathrm{P200_T}$; $r=.442$, $p<.005$,for P200 latency). It is inferred from these results and those reported by other authors that P200 reflects the process of encoding or transferring information from a sensory register into short-term memory (STM). Further, it is argued that inspection time indexes the rate at which sensory input is sampled in the initial stages of information processing.

Several techniques were used to examine the relationship between the P300 component and IT. P300 latency was not closely related to IT, but P300 amplitude correlated positively and significantly with IT (Experiment 6). P300 amplitude reflected subjects' confidence in their performance of a task, and this result suggests that subjects' choice of a more stringent criterion of confidence for their judgments may contribute to their longer measured ITs.

Another factor which may also play a part in subjects' performance in the IT task is the process of anticipation of task stimulus. When the warning period was extended from 500 msec to 1800 msec (in Experiments 4 and 5), it was found that the strength of anticipation, as indexed by the amplitude of contingent negative variation (CNV), correlated positively with IT. This suggests that strong anticipation may, under these conditions, handicap

subjects' performance on the IT task.

Experiment 6 examined the relationships between IQ, IT and the measures of AEPs previously found to correlate with IT. Each subject was presented with his/her IT-duration stimulus. Half of the presentations were designated as "task-loaded" trials requiring an IT response, and the other half the "task-free" trials requiring no IT response, with the two kinds of trials randomly intermixed. In each trial, subjects were asked to give a reaction-time response to a visual signal following the IT-duration stimulus.

In this experiment, as expected, IT correlated negatively with intelligence test scores. The previously identified parameters of AEPs to the IT-duration stimulus with task requirements correlated with IT, but not IQ; these therefore reflect task-specific individual differences. In contrast, measures of the P200 to the digit stimuli which identified the nature of a trial (i.e. with or without IT-task requirements) did correlate with IQ, and reflect individual differences related to general cognitive ability. Subjects' inspection time also correlated with the non-specific AEP differences.

In the light of the results described above, the IT-IQ relation may be seen to depend on a general speed factor, reflecting the process of encoding sensory input into STM from a sensory register. The higher the speed of this encoding process (i.e. smaller values of the P200 temporal measures), the shorter the inspection time and the higher the intelligence test score.

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CHAPTER 1

INTRODUCTION

For over a century, psychologists have made many attempts to base the measurement of intelligence on physiological or perceptual processes with a minimum of specifically psychological content. Simple and choice reaction times, average evoked potentials, critical flicker frequency, and other non-cognitive measure have been harnessed to try to bring to light the basic elements of intelligence (Galton, 1883; Peak & Boring, 1926; Boring, 1957; Ertl & Schafer, 1969; Jensen, 1980, 1982). Recently, many researchers in this area have been attracted to the relationships between mental speed measures, evoked potentials and intelligence test scores (Berger, 1982; Brand & Deary, 1982; Hendrickson, 1982; Jensen, 1982; Mackintosh, 1981, 1986; Robinson *et al.* 1984).

There is considerable evidence to support the view that a mental speed measure, called 'inspection time' (IT), correlates with intelligence measures (IQ) (Vickers *et al.* 1972; Brand & Deary, 1982; Longstreth *et al.* 1986; Lubin & Fernandez, 1986; Nettelbeck *et al.* 1986a). Nettelbeck *et al.* (1986b) conclude that, after correcting for restriction of variance in IQ in most study populations, the best available estimate of the strength of association between inspection time and adult IQ, as measured by a variety of tests, is about -0.50. This raises questions about the basis for the correlation between inspection time and intelligence and the nature of the differences in information processing that are revealed by the differences in the speed of perceptual system in the inspection time task. For instance, it may be asked: are there differences in subjects' anticipation or attention that are responsible for the correlation between inspection time and intelligence (Mackintosh, 1986); or is the IT-IQ association attributable to differences in the speed of sensory information encoding and/or evaluation (Vickers *et al.* 1972; Nettelbeck, 1982; Vickers & Smith, 1986)? At present, however, as Vernon (1986) points out, the only statement that can be made with any certainty is that the inspection time measure has a moderate correlation with intelligence and that considerably more research will be required before the meaning of the correlation is made clear (Nettelbeck *et al.* 1986a).

Therefore, it seems that what is necessary at this stage is exploratory studies which look for evidence that any or all of these processes differ between subjects in a way that can be related to their differences in IT task performance. In this way, the nature of the differences revealed by the IT task, so far little understood, can be investigated in detail. Because so little is known of what differences to look for, both positive or negative results can be important to the questions under investigation. With this aim in mind, the present study will investigate the differences between subjects in IT task performance in relation to their cortical evoked potentials produced by IT task stimuli. This approach promises to be fruitful because many studies have shown that: on the one hand, the cortical evoked potentials can act as correlates, to some extent, of the processes of mental activity such as anticipation, encoding and evaluation (Walter *et al.* 1964; Squires, K.C. *et al.* 1977; Squires, N.K. *et al.* 1977; Chapman *et al.* 1978; Pritchard, 1981; Naatanen, 1982); and, on the other hand, they may be related to subjects' intellectual ability (Chalke & Ertl, 1965; Obsorne, 1969; Callaway, 1975; Hendrickson, 1982; Haier *et al.* 1983; Fraser, 1984; Robinson *et al.* 1984).

Most psychologists are sufficiently familiar with the wider arguments about intelligence tests, and there is little need to rehearse them here. I shall therefore restrict my review discussion to those theories and studies which are closely related to the present concerns. The following sections of the introduction review briefly the background knowledge about evoked potentials and inspection time, and the existing theories which have been postulated to link these to intelligence are in turn reviewed briefly. The characteristics of the present study are described in the last section. To avoid endless qualification, the term intelligence will be used as equivalent to IQ throughout the thesis, unless stated otherwise.

1.1. Average evoked potentials

1.1.1. The average evoked potential

The evoked potential (EP), or event-related response (ERP), is the electrical response of the brain to a brief, peripherally applied stimulus (Adrian & Matthews, 1934; Adrian, 1941; Shagass, 1972). A pulse of light, a shock, brief touch, or a click will elicit an evoked cerebral response, by way of the respective sensory pathways, which has a definite relationship to the occurrence of specific stimuli. Unfortunately, the 'signal' provided by any single EP tends to be obscured by the 'noise' of the spontaneous EEG activity and progress depends on the development of techniques which improve the signal-to-noise ratio.

The most commonly used procedure to achieve this goal is the signal averaging technique, which was introduced into this field by G.D. Dawson more than thirty years ago (Dawson, 1951, 1954). A stimulus is repeated a number of times, and on each occasion an epoch of EEG is recorded, each epoch having the same temporal relationship with the stimulus. The epochs are then averaged by a computer. Evoked potentials having a consistent time-relationship with the stimulus will summate, while spontaneous EEG activity, which is not time-locked to the stimulus, will tend to average to zero (Shagass, 1972). The improvement in signal-to-noise ratio so obtained is roughly proportional to the square root of the number of trials averaged (Picton & Hink, 1974). Thus, the technique of averaging or summing, whereby previously obscure cerebral electrical changes to stimuli can be extracted by computer from the brain's background 'noise' or ongoing electrical activity by relating them to time of the stimulus, provides a close look at the brain's electrophysiology.

There are two conventional ways of presenting evoked potentials, namely, plotting the positive potentials upwards or downwards. In this study, the positive potentials will be plotted upwards. Fig. 1.1 shows an average evoked potential (AEP), which is derived from a number of evoked potentials elicited by visual stimuli. The figure is highly schematic, and the identification of a peak or a trough in reality is not as easy as it might appear. The polaric-latency labelling system (Donchin *et al.* 1977) is used. In this labelling system, the peaks and troughs in the averaged waveform are labelled 'P' or 'N', depending on whether they were positive or negative, the P or N being followed by a number indicating the latency in milliseconds from the stimulus onset. Thus, P200 represents a positive deflection with a latency of 200 milliseconds measured from stimulus onset, and N150 represents a negative deflection with a latency of 150 milliseconds measured from stimulus onset. However, the very precision of timing implied by this nomenclature can be misleading at times. The latency of an AEP component may vary with the time required for perceptual processing, which might be different from one person to another. To allow for such variability, some authors have suggested

A visual AEP

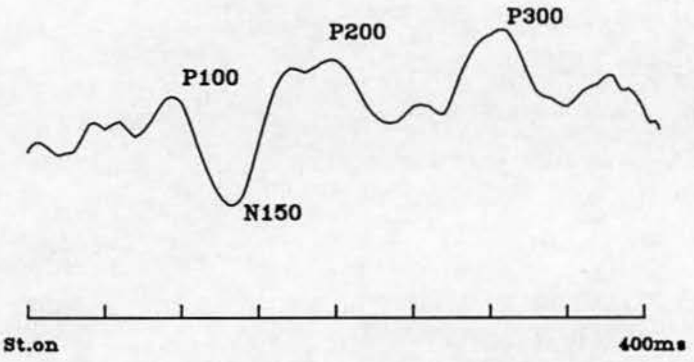

Fig. 1.1 A diagrammatic visual average evoked potential recorded from vertex. Positivity upwards.

that theoretical components may be identified by their characteristic latency, and a superimposed line is used to show that such an identification is theoretical rather than observational, for example, $\overline{\text{P200}}$ (Picton, 1980). To make life easier, I shall, in this thesis, leave out the superimposed line, and simply use, say, P200 to show its theoretical identification.

1.1.2. Problems of averaging

The formal requirements of the averaging process are that the ERPs be identical with each event, and that the EEG 'noise' be normally distributed about a mean and independent with each repetition. These requirements are not always met during the recording of evoked potentials, and some distortion may result. For instance, amplitude and latency distortions may occur if the ERPs are not consistent with repetition. Some aberrant recordings, or outliers, might be observed and their existence in the averaged waveform may obscure the expected positive and negative peaks (Picton, 1980). Disturbances from the mains of electricity supply can also cause the distortion of ERPs.

In this study, the problem of aberrant recordings was assessed using cluster analysis in some experiments (e.g. in Exp. 3). Disturbances from the mains of electricity supply were assessed by spectral analysis and overcome by using the technique of moving averaging (Chatfield, 1980). The third problem tackled in the study concerned the minimum number of evoked potentials to be averaged so that a reasonably reliable AEP may be obtained from a particular ERP recording setup.

As a technique for evaluating human ERPs, therefore, averaging is not perfect. John (1973) has pointed out that averaging may, in fact, obscure event-related potentials. He found that individual ERPs to identical stimuli, recorded from electrodes implanted in cats, may be quite different. As John puts it: "Noise.... may not be noise but only poorly understood signals." Nevertheless, provide one is aware of its limitations, averaging remains the most powerful and reliable technique available and indispensable for the study of human ERPs. As Granit (1977) said, "In connection with different psychologically defined operations the method of averaging is of interest for problems concerning timing, direction, and elementary localization of otherwise inaccessible processes. It can be used also to measure the intensity or degree of a process and is thus a valuable asset for the science of psychophysiology."

1.2. AEP as a biological correlate of IQ

For years investigators have looked for a relationship between brainwave patterns and levels of intelligence as measured by psychometric tests of ability. While some have reported significant correlations between various parameters of the EEG and intelligence test scores, others have been unable to demonstrate such a relationship. These contradictory findings have been discussed by Vogel and Broverman (1964) and Ellingson (1966). While Ellingson argues that the evidence concerning the relationship between EEG waves and intelligence is contradictory and inconclusive, Vogel and Broverman stress that there is reliable evidence to support the existence of such a relationship. However, whatever the reasons might be (Callaway, 1973), the efforts to relate ordinary EEG to intelligence have almost ceased, and at present the average evoked responses seem to offer a more promising approach to the question under discussion, not least because the AEP configuration can be more easily measured than that of spontaneous EEG waves (Eysenck & Barrett, 1985).

1.2.1. Ertl's theory of neural efficiency

Encouraged by the first study looking at the relationship between IQ scores and the AEP latency measure (Chalke & Ertl, 1965), Ertl and Schafer (1969) hypothesized a concept of neural efficiency, which is defined as 'the latency of the most probable times of occurrence of a sequence of spike discharges following the stimulus'. They viewed the components of the AEP as the electrical signs of information processing or associative activity in the brain. On this basis it would be reasonable to postulate that a biologically efficient organism should process information more rapidly than a less efficient organism. Thus, the delay or latency of the AEP components is the measure they used of the efficiency of this process.

Several studies have confirmed Ertl and Schafer's work and discovered correlations in the region of 0.3 between IQ and AEP latency (Galbraith *et al.* 1970; Shucard & Horn, 1972; Callaway, 1973; Hendrickson, 1973). Other investigations have found no evidence for such a correlation between IQ and AEP (Davis, 1971; Ertl, 1971; Dustman & Beck, 1972; Engel & Henderson, 1973; Rust, 1975).

One of the reasons which have been put forward to explain these rather contradictory findings concerns Ertl's (1965) zero-crossing latency measure. This latency measure counts in a subject's ERP recordings the number of pulses passing from positive to negative voltage (zero-crossing analysis) (Ertl, 1965). If the number of zero-crossing counts exceeds the mean by two standard deviations a statistically significant peak is thus identified. Callaway (1973) attributes Ertl's findings to this peculiar way of measuring the latency of AEP components and also suggests that short latencies in bright subjects may reflect their more rapid loss of interest in dull repetitive stimuli. This suggestion was based on the observation that latency-IQ correlations were low early in the experimental session when subjects were pressing a switch to each light flash and better later in the experimental session when the subject was not carrying out any assigned task and was, perhaps, bored (Shucard & Horn, 1972). In other words, the average size of the IQ-latency correlation, as well as the number of significant correlations, was increased as these conditions of evoked potential testing that tended to impose alertness on subjects were relaxed.

Other possible reasons for the confusing findings of the IQ-latency relation may involve the use of subjects selected for their high and low IQs and bipolar electrode placement. More details can be found elsewhere (Eysenck & Barrett, 1985).

1.2.2. Hendrickson's pulse train hypothesis

The Hendrickson and Hendrickson's (1980) model hypothesizes that those individuals with noisy neural channels will produce AEPs of a smoother appearance than the AEPs obtained from individuals with less noisy channels. They view individuals as differing in the number of errors made in neural transmission. Those individuals with few transmission errors will have evoked potentials whose stimulus characteristics are similar. Those with a higher average rate of transmission error will have evoked potentials that vary more due to a greater number of random transmission errors that introduce more noise into the signal. Consequently, the string-length (so-called because it could, in principle, be measured by placing a string over the AEP waveform for a given epoch), corresponding to the complexity of the AEP, will be shorter in AEPs from less intelligent subjects. Hendrickson and Hendrickson (1980) analysed some published data of Ertl's and obtained a correlation of 0.77

between subjects' IQ scores and their string-length measures.

Several investigations have found empirical evidence in favour of this model (Blinkhorn & Hendrickson, 1982; Haier *et al.* 1983; Fraser, 1984). Hendrickson (1982) used the Wechsler Adult Intelligence Scale (WAIS) to assess the IQ of 219 children and found a correlation of 0.72 between total IQ score and AEP string-length measure. A correlation of 0.72 between IQ score and variance of the AEP was also reported. Mackintosh (1986) has argued that, as the variability between trials will cancel out peaks and troughs in the average record (Israel *et al.* 1980) and lead to a flat average trace and low score on the string-length measure, the string-length and variance should be negatively correlated (as they were). The Hendricksons' string-length correlations with IQ may at least partly reflect the stability and uniformity of the subject's response over trials of listening to the stimulus. Mackintosh (1986) believes that one might want to attribute uniformity across trials to factors such as subjects' willingness to comply with instructions or their ability to maintain concentration on a remarkably tedious task, and that this might be responsible for the observed correlations.

1.2.3. Schafer's model of cognitive neural adaptability

Several researchers have shown that there is a tendency for unexpected stimuli to produce AEPs of larger overall amplitude than those generated using stimuli whose nature and timing is known by the individual (Schafer, 1978; Israel *et al.* 1980; Schafer *et al.* 1981). This empirical observation of the modulation of AEPs' amplitude is thought to be due to 'cognitive neural adaption' (Schafer & Marcus, 1973). Schafer (1982) relates this cognitive neural adaptability to individual differences in intelligence. He hypothesizes that the physiological basis of this relationship is neural energy as defined by the number of neurons firing in response to a stimulus. A functionally efficient brain, according to this theory, will use relatively few neurons to process a known stimulus, whereas for a novel, unexpected stimulus the brain will commit a larger number of neurons. It is suggested that this commitment of neural energy can be observed as amplitude differences between AEPs elicited under various stimulus presentation conditions. Schafer defines an operational measure as the observed variations around an individual's 'average amplitude'. The average amplitude is the mean amplitude across the relevant experimental conditions. Thus, individuals with high neural adaptability, characterized by AEPs with much smaller than average amplitude to expected stimuli, should show high intelligence test scores. Conversely, for individuals with low neural adaptability, the size of AEP amplitude modulation should be diminished with correspondingly low intelligence test scores.

Schafer (1982) recorded subjects' ERPs under four conditions. Condition 1 was named self-stimulation (SS), in which subjects delivered clicks to themselves by pressing a hand-held microswitch. Subjects were asked to deliver the stimuli randomly in time. The stimulus events were recorded for subsequent playback in condition 3. In condition 2, periodic stimulation (PS), clicks were presented regularly at the rate of one every 2 seconds. In condition 3, machine stimulation (MS), recorded stimulus events generated in condition 1 were replayed to same subjects through the control of a computer. Condition 4 was a self-stimulation control condition, in which the subject pressed the microswitch, but received no stimulus. 76 subjects' IQs were assessed using the WAIS, yielding a mean IQ of 118, with a range from 98 to 135. Two sets of AEP scores were obtained for each subject. The total integrated amplitude[1] of each AEP from each condition (SS, PS and MS) was expressed as a ratio of each subject's average AEP amplitude. Average amplitudes (AV) were then computed from the sum of the integrated amplitude AEP measures under all three experimental conditions divided by the number of conditions: i.e. AV=(SS+PS+MS)/3. A neural adaptability score was computed for each subject using the formula NATS=[(MS-SS)/AV]+50. Table 1.1 shows correlations reported in Schafer's study.

Table 1.1
Correlations between AEP amplitude ratio, neural adaptability T score, and IQ

	WAIS score			NATS
(N=76)	full IQ	VIQ	PIQ	
NATS	.66	.63	.44	
Periodic/Average	.40	.38	.25	.63
Self/Average	.44	.42	.31	.60
Machine/Average	.65	.61	.43	.97

(Note: data from Schafer, 1982.)

The results support Schafer's hypothesis. The higher the IQ, the greater was the amplitude difference between MS and SS AEP amplitude. However, it is hardly possible to compare Schafer's findings with those reported by others because they were calculated in an unique way.

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[1] An integrated amplitude of an AEP is the sum of the peak-to-peak amplitudes of the identified components of that AEP.

1.2.4. Summary

It appears that the three theories of the AEP-IQ relation have something in common, namely, they all consider brainwaves to reflect some general property of an human brain with respect to intelligence. This theoretical approach is different from that of the present study, which would rather assume that different components of AEPs may reflect different mental operations of information processing, such as anticipation, encoding, evaluation, response execution and the like (see Section 1.5.2). In this thesis, therefore, I shall not set out to try to link the results obtained in this study to the theories of the AEP-IQ relation described above, despite the fact that some results may provide evidence in favour of the Ertl's theory (e.g. in Exp. 3 and 6).

1.3. Inspection time

1.3.1. Definition and measurement of inspection time

The procedure for estimating 'inspection time' was developed within the framework of a cumulative processing model of discrimination advanced by Vickers *et al.* (1972). This model assumes that, following the sensory registration of the briefly presented stimuli, evidence is encoded into short-term memory (STM). The accumulation of a critical amount of evidence in support of one of the possible alternatives determines when a decision is made. Further encoding is required to translate the decision outcome into a response. Some minimal time is required to complete even the simplest perceptual discrimination task since the rate at which information is sampled is assumed to be limited. The minimum time required by an individual to take one sample is termed the 'inspection time' (IT) (Nettelbeck, 1982; Vickers &

Smith, 1986).

In practice, an estimate of inspection time is made by having subjects make perceptually simple discriminations between alternatives in a two-choice task. Most frequently, the task involves brief presentations of two vertical lines side by side, one approximately 50 percent longer than the other (Nettelbeck & Lally, 1976; Lally & Nettelbeck, 1977; Nettelbeck, *et al.* 1979; Brand & Deary, 1982). The marked difference between the two lines makes the task perceptually simple because the difference subtends a visual angle at the viewing position that far exceeds available estimates of 'noise' in visual system (Vickers *et al.* 1972). If each of these tachistoscopic exposures is followed by a backward mask, then it is assumed that encoding from iconic storage of input to short-term memory is interrupted by the backward mask (Neisser, 1967; Saccuzzo *et al.* 1979), and is thus limited to the time between the onset of the stimulus and that of the masking figure. Seated in front of a tachistoscope or stimulus display box, the subject's task is simply to say whether the longer line is on the left or the right. The measured IT is then defined as the minimum exposure duration necessary for a given high accuracy criterion in subjects' judgments. Usually, it is between 90 and 97.5 percent correct responses (Nettelbeck *et al.* 1980; Hulme & Turnbull, 1983).

One method of measuring IT, known as the method of constant stimuli, involves presenting stimuli at different durations in a random order or in blocks of trials with each succeeding block being of a shorter stimulus duration. Inspection time has been computed as the stimulus duration at which a subject could make a correct discrimination on 97.5% of all trials. This estimate has been obtained from an ogive fitting procedure which provides the best fit to the pattern of correct responses obtained at the various stimulus exposure durations.

Another method designed to yield a more economical measure of inspection time is that involving a computer-controlled sequential estimation procedure derived using a staircase refinement of the method of limits, i.e. Parameter Estimate of Sequential Test (PEST) (Taylor & Creelman, 1967). With this method, the experimenter controls the exposure duration of the first stimulus, the exposure durations of subsequent stimuli being increased or decreased by a computer program according to the accuracy of the subject's responding in relation to a predetermined target level of accuracy. When the subject's responding increases beyond this level of accuracy, the stimulus duration decreases in a stepwise fashion. Conversely, as responding falls below this level, stimulus duration increases. The step sizes become progressively smaller as the target level of accuracy is reached so that most judgements are made at exposure durations very close to the target level. This has the advantage of requiring the subject to complete only as many trials as are necessary to determine the stimulus duration where response accuracy equals to the criterion level (Wilson, 1984). It is this method that will be used in the present study for the estimation of subjects' inspection time.

1.3.2. Problems with IT estimation

Most recently, it has been suggested that cognitive strategies may confound the measure of inspection time (Brand, 1984). Some studies (Nettelbeck & Lally, 1976; Smith & Stanley, 1983; Mackenzie & Bingham, 1985; Mackenzie & Cumming, 1986) have provided evidence that subjects may be able to use various strategies, thereby reducing the effectiveness of this measure as a valid, non-cognitive index of ability. A full discussion of the problems which are purported to handicap the IT measure is beyond the scope of this thesis. The question is discussed fully elsewhere (Egan, 1986). Nevertheless, it has been suggested that this source of trouble may be overstressed (Egan, 1986).

1.4. Inspection time and intelligence

1.4.1. What does the IT measure measure?

There are two current theories of what it is that inspection time measures. Mackenzie & Bingham (1985) have differentiated the two theories as Nettelbeck's vs Brand's. From their point of view, Nettelbeck's position views the inspection time as a measure of the rate of sampling of sensory input in the initial stages of information processing (Vickers *et al.* 1972), whereas Brand's position treats the IT measure as an overall level of 'mental speed'.

I would like to point out that Mackenzie and Bingham seem to have forgotten the fact that Brand did suggest that the IT measure reflects the speed at the 'intake' stage of information processing (Brand & Deary, 1982; Brand, 1984). Mackenzie and Bingham may be able to tell the difference between the terms 'initial' and 'intake', but I can not. Thus, I would like to think both groups (Nettelbeck's in Adelaide and Brand's in Edinburgh) share the same idea, i.e. that the inspection time measures the speed of sensory information intake or encoding (Vernon, 1981). To be more specific, I would rather view the IT measure as a function of the rate at which sensory information in iconic storage or in the sensory register is encoded or transferred into short-term memory (Saccuzzo *et al.* 1979; Nettelbeck, 1982).

As a measure indexing the process of stimulus intake, the IT paradigm would appear to have good face validity. Kirby and McConaghy (1986) have provided empirical evidence for the validity of inspection time as a measure of the input process. Moreover, research has shown it to be a fairly stable measure over time: correlations between repeated measures using both retarded and non-retarded subjects separately have almost always been statistically significant, ranging from 0.25 to 0.98 (Nettelbeck, 1982; Kirby & McConaghy, 1986).

1.4.2. Reported IT-IQ correlation coefficients

Although some studies have shown remarkable correlations, ranging up to -0.92 (Nettelbeck & Lally, 1976; Brand & Deary, 1982; Longstreth *et al.* 1986), it seems that there is probably a modest inverse relation (r=-0.20 to -0.50) between IT and various measures of IQ (Brand, 1984). There are a few exceptions (Vernon, 1981; Irwin, 1984). For example, Smith and Stanley (1983) examined the IT-IQ correlations among schoolchildren. They found that the correlations were uniformly non-significant and mostly positive. A recent summary of the IT-IQ correlations can be seen in Lubin and Fernandez (1986). One criticism over the reported IT-IQ correlations is that some earlier studies included a disproportionate number of retarded subjects in their samples (Nettelbeck & Lally, 1977; Lally & Nettelbeck, 1980; Nettelbeck, 1982). More issues concerning the IT-IQ relationship are discussed elsewhere (Vernon, 1986).

In a concise summary of the studies of the IT-IQ relation, Mackintosh (1986) suggests that it might be reasonable to argue that a modest, but significant, negative correlation between IQ and IT implies that intelligence is partly a matter of 'mental speed' and that mental speed is measured by inspection time. He points out that one problem with this suggestion is that several studies have reported negligible correlations between IT and other supposed measures of mental speed such as reaction times (Vernon, 1981). For example, Vernon (1983) reported a correlation of 0.11 between reaction time and inspection time. In Smith and Stanley's (1983) study, the IT correlation with 8-choice reaction time was 0.06. Vernon (1986) concludes that the IT measure does not fit neatly into models accounting for the correlations between reaction time and intelligence and indicates that additional research will be required to obtain a better understanding of the nature of the IT-IQ relationship (Nettelbeck *et al.* 1986a). This raises the question of how to obtain evidence that will help us understand the nature of IT-IQ relationship. Unfortunately, the common approach to the IT-IQ relation seems incapable of telling us more than that the inspection time does correlate negatively with intelligence in general, and/or with the scores of some IQ subtests in particular (Mackenzie & Bingham, 1985; Nettelbeck *et al.* 1986a).

1.5. Purposes and characteristics of the study

1.5.1. Purposes of the study

Although there are many studies which have intended to discover whether there is a relationship between intelligence test score and either AEP parameters or the IT measure, published reports up to now have not tried to investigate all the three variables at the same time. If such studies were done, they might have unearthed some facts that could help us understand the nature of the IT-IQ relation. In this study, therefore, I shall use AEP techniques to investigate the mental processes that are responsible for the widely-observed IT-IQ correlations. To be more specific, I would like to see whether or not any parameters of the AEP components can be related to both subjects' performance on the IT task and their intellectual ability measured by intelligence tests.

1.5.2. Characteristics of this study

The present study is different from most other studies of the IQ-ERP relation in two ways. First, it adopts a different hypothesis when compared with the other investigations. As it involves an attempt to relate the rate of encoding sensory information from iconic storage to STM (measured presumably by the inspection time) to specific parameters of the AEPs, the three hypotheses (described earlier) concerning the relationship between AEP measures and IQ scores are not immediately relevant.

Nevertheless, most researchers investigating the relationship of human brainwaves to mental processes rather than to intellectual ability have adopted the approach of information processing (Broadbent, 1958) and attempted to link particular AEP components to mental processes (Donchin, 1981; Pritchard, 1981; Donchin, 1984; Hillyard, 1984). The very general hypothesis adopted in these investigations is that brain waves can be useful as indicators (at least of the end) of a mental process (Woodworth, 1938). Although this hypothesis at first glance seems simple, even naive, it meets the intention and requirements of the study.

Second, when evoked potentials are collected they commonly use stimuli which demand no attention (Eysenck & Barrett, 1985). The ERPs in this study were recorded under conditions in which subjects were actually performing either an IT task or an equivalent task. There are two reasons for this. First, an AEP component corresponding to a mental process might stand out more distinctly when that mental process is working (Sutton *et al.* 1967; Donchin, 1984). Second, according to our common sense of how intellectual behaviours manifest themselves it seems to be more comprehensible to investigate the characteristics of brainwaves with respect to the brightness or dullness of a brain, when that brain is active (Chapman *et al.* 1978).

CHAPTER 2

A PILOT STUDY

2.1. Introduction

As has already been said in Chapter 1, one of the goals of the thesis is to examine the relation between the AEP and the IT measure. Therefore, the question of what the average evoked potential looks like, when subjects are performing the inspection time task, must be addressed first. One of the purposes of this pilot study is to see if there exists any AEP component which occurs distinctively in the IT paradigm. The other purpose is to estimate some parameters relevant to the recording and averaging of ERPs. For instance, how many samples are needed to ensure a reliable AEP? Since this study is, to my knowledge, the first study which has set out to analyse subjects' ERPs produced by IT task stimuli in relation to their inspection time, the first aim is self-explanatory and nothing more needs to be said about it. In the following sections of this introduction, I shall only discuss the second aim in detail.

2.1.1. The problem of the number of samples

Ever since the averaging technique was introduced into the field of psychology (Dawson, 1954), the number of samples that should be collected and summated in order to obtain a reliable AEP under a particular experimental environment seems to have been arbitrarily defined by custom or convenience, rather than by objective criteria (Vaughan, 1974).

From the principle of averaging, it could be assumed that the more observations, or samples, that are used for averaging, the better resultant AEP should be. This is due to the improvement in the signal-to-noise ratio.

Collecting many samples may appear easy to do in principle. In reality, however, there are always one or more constraints. For instance, the time available with subjects is usually limited. And on the other hand, various undesirable effects might occur within a long run of recording. In a model of evoked potentials (Vaughan, 1974), total voltage recorded over a time epoch is as follows:

$$V(t)=E(t)+e(t)+G(t) \qquad (1)$$

where V(t) is the total voltage recorded over the epoch, E(t) is the mean component of the ERP, e(t) is its variable component, and G(t) is the background EEG. Both e(t) and G(t) are supposed to be stationary processes which show no systematic change with time. If the recording duration is too long, some systematic changes of e(t) and G(t) might occur, due to the effects of habituation and/or physiological fatigue (Uttal, 1965; Ritter *et al.* 1968; Donald, 1979; Walrath & Hallman, 1984).

There are several methods available (Vaughan, 1974), which may be used, prior to an experiment proper, to offer guidelines so that an investigator can choose the number (N) of samples to be collected in a particular ERP recording environment. By averaging, the improvement in the ratio of signal to noise is roughly proportional to the square root of the number of samples averaged (i.e. $N^{1/2}$ rule) (Yule, 1937; Picton & Hink, 1974). One method is to derive from a large number of samples a mean, or range, of standard deviations across time samples of sampling epoch. Then, the $N^{1/2}$ rule is applied to that mean to find an ideal value of the N. For example, if the observed mean of standard deviations derived from N_0 samples is S_0, divide S_0 by $N^{1/2}$, where N less than N_0. As N increases, the quotient, which is the mean of standard errors across time samples of AEP, will decrease. For a given mean of the standard error of AEP, a particular N can be determined accordingly. The second method is to collect a raw EEG sample and find out its standard deviation from zero, since the major variance of an AEP is ordinarily contributed by G(t). Then, the $N^{1/2}$ rule is used to estimate a standard error which leads to the selection of the N in the same way as described above. The third approach is to find out the ratio of signal amplitude to noise amplitude and multiply it by $N^{1/2}$, in order to obtain a signal-to-noise ratio of at least 2 (Picton & Hink, 1974). The idea behind these methods is that if the N is chosen in such a way and employed as the criterion for averaging, then a given signal-to-noise ratio should result.

Nevertheless, there is a problem which is common to these methods. That is, these methods do not disclose empirically any information about the residual in the averaged response of the background 'noise' which is assumed to summate to zero. Is it possible to set up a procedure which takes into account the residual of background 'noise' and defines the N accordingly?

2.1.2. Theoretical and empirical considerations

For the objective detection of cortical auditory evoked potentials a simple method has been proposed from a statistical point of view, which allows on-line estimation of the number of the samples required to reach detection criterion (Schimmel & Cohen, 1974, 1975; Wong & Bickford, 1980; Elberling & Don, 1984). The method involves a calculation of the ratio, called the P value (Wong & Bickford, 1980), of the variance of the epoch in the averaged response waveform to the variance of the background noise that is estimated by the +/- reference technique, i.e., alternate addition and subtraction

(Schimmel, 1967).[1] This is expressed as (Wong & Bickford, 1980):

$$P = Var(A_N)/Var(A'_N) \qquad (2)$$

where $Var(A_N)$ is the variance of a mean response of N sweeps (samples) recorded for detecting the auditory brainstem response and $Var(A'_N)$ is the variance of the residual waveform of N sweeps estimated by the +/- reference.

What interests me in this approach is that its application is valuable in the sense that it maximizes the efficiency of recording session by avoiding the averaging of excessive or insufficient numbers of samples. This method has been successfully used to detect efficiently auditory brainstem responses (Don *et al.* 1984; Mason, 1984) and somatosensory evoked cortical responses (Cullity *et al.* 1976). Can it be applied to the problem of defining the N in the present situation, in which the on-line estimating of the N is not appropriate?

Examining both equation (2) and equation (1) together, it can be seen that the numerator in equation (2) can be at least theoretically separated into two parts, expressed as follows:

$$Var(AEP) = Var(E(t)) + Var(e(t),G(t)) \qquad (3)$$

where Var(AEP) [i.e. $Var(A_N)$] is the variance of the average evoked potential, Var(E(t)) is the variance of the average of mean component E(t), and Var(e(t),G(t)) is the variance of the average of the e(t) component, G(t) component, and their interactions.

---

[1] By adding and subtracting alternative ERP samples, the +/- technique cancels out all the time-locked signals and retains the residual 'noise' waveform, which should be the same as that in the corresponding AEP waveform obtained by using the averaging procedure. See Schimmel (1967) for the detail.

Joining the equation (2) and equation (3), and using Var(noise), instead of $Var(A'_N)$, to express the variance of the residual waveform estimated by the +/- reference of background noise, thus we have:

$$P = [Var(E(t)) + Var(e(t),G(t))]/Var(noise) \qquad (4)$$

As e(t) and G(t) are not time-locked responses, they will summate to zero by either addition or subtraction, or both. The idea here is that as these waves are out of phase with one another the use of either addition or subtraction, or both, should not affect the outcome (Schimmel, 1967). Thus, the Var(e(t),G(t)) is theoretically identical with the denominator Var(noise), variance of residual waveform, estimated by the +/- reference, of background noise. The P value can be more generally expressed as :

$$P = 1 + Var(E(t))/Var(noise) \qquad (5)$$

Since theoretically the E(t) is stable and consistent in each individual epoch (Vaughan, 1974), the Var(E(t)) should be independent of the number of samples being, or to be, averaged (Picton & Hink, 1974). The main task of calculating P value centres on the estimate of Var(noise). As the Var(noise) is inversely proportional to N (Schimmel, 1967) and presumably approximate in reality to a horizontal line being close to zero when N is increased, therefore, plotting Var(Noise) against the number of samples being averaged may enable us to solve the problem of defining the number of samples to be observed in an experiment proper.

2.2. Method

2.2.1. Subjects

Four male university students ranging in age from 20 to 30 years were subjects.

2.2.2. IT stimuli

IT stimuli were presented by a light emitting diode display (LED), driven by a PDP11/34 computer. A horizontal bar 18mm long in the low part of the panel on the front of the display box provided an attentional cue, which occurred 500 msec before stimulus onset and lasted for 300 msec (Diagram 2.1).

Stimuli were similar to those described by others for the inspection time paradigm (Vickers *et al.* 1972; Netterlbeck & Lally, 1976; Brand & Deary, 1982; Bain, 1983), consisting of two vertical lines 26mm and 13mm long, and 18mm apart, with their upper ends linked by a horizontal line. Following the exposure of the stimulus display to be discriminated, a rectangular display 26mm long and 18mm wide then overlayed the discriminative stimulus and acted as a backward mask. (For convenience, from now on the joint stimulus, i.e. the discriminative stimulus plus the following mask, will be called test stimulus or test stimulus display.) The duration of the test stimulus (i.e. from the onset of the discriminative stimulus to the offset of the mask) was 600 msec. The display was viewed from an easy reach distance, and subjects were asked to make their judgments in their own time by pressing one of two levers which are fixed at the front of the LED box. In this pilot experiment, the response required of the subjects was counterbalanced: two subjects were asked to press the lever on the side at which the longer vertical line had appeared in the discriminative stimulus, and the other two responded to the shorter vertical line. A program used the standard DEC FORTRAN random

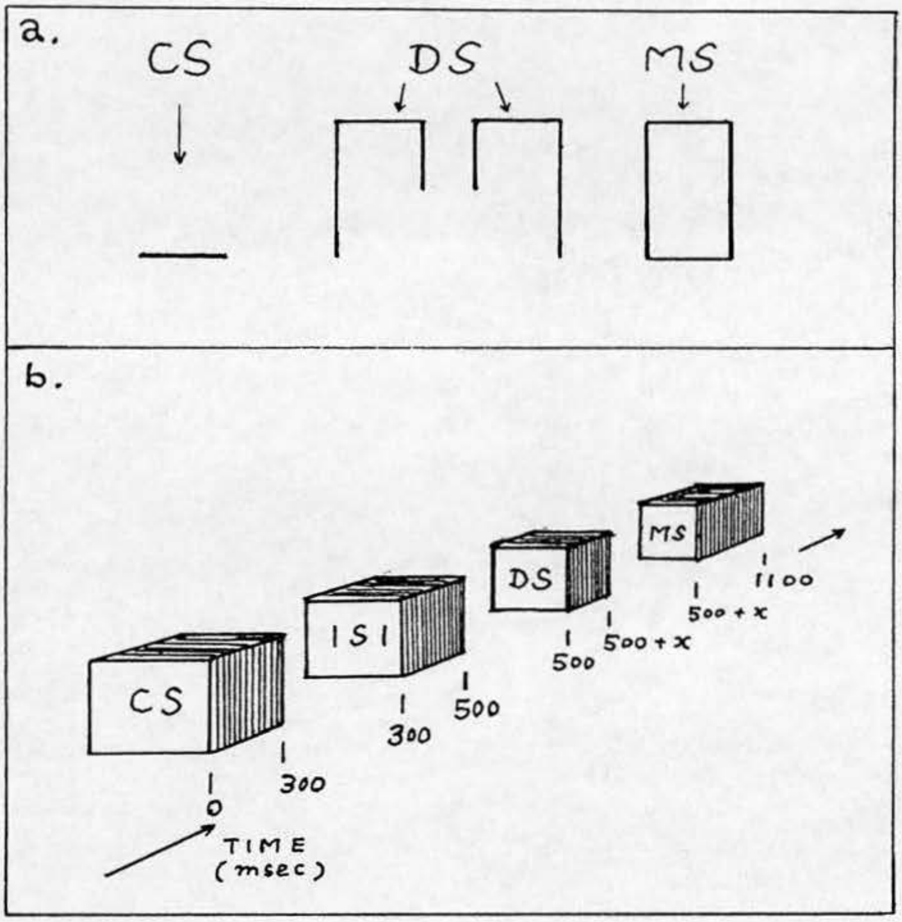

Diagram 2.1

Diagram 2.1a shows the patterns of stimuli used. Diagram 2.1b outlines the procedure. CS: cue signal; ISI: inter-stimulus interval; DS: discriminative stimulus; MS: backward mask.

number generator to select randomly which type of stimulus (longer line on left, or on right) was shown on each trial, and also to set an inter-trial interval that had varied randomly over the range of 2 to 3 seconds between subjects' response and presentation of next cue signal.

2.2.3. ERP data recording

Silver/silver chloride cap electrodes were attached at vertex and to both mastoids using collodion. ERPs were recorded with the active electrode being the vertex electrode [C_z in the 10-20 system (Jasper, 1958)] and the reference being the electrode on the left mastoid. The right mastoid acted as earth. All recordings were collected through a PA-300 EEG amplifier (Biodata Ltd) and stored in RK05 discs for off-line analysis. The gain of the amplifier was set at 500 and the frequency passband was 0.2Hz to 1KHz. The computer sampling rate was 1KHz with an epoch of 1024 msec, starting from the cue onset. The A/D converter had a word length of 12 bits (Picton & Hink, 1974).

Discriminative stimuli that had a duration equal to a subject's IT estimate and which were followed immediately by the mask were used to elicit ERPs from the subject. (For simplicity, I shall refer this type of test stimulus as the IT-type stimulus from now on.) For each presentation of the IT-type stimulus, the subject was asked to respond in the same way as in the previous session of IT estimation, i.e. press the lever on the side at which the longer (or shorter) line had appeared in the display of the discriminative stimulus. A total of 215 ERP samples were obtained from each subject evoked by the presentation of their IT-type stimuli, which had a total exposure duration of 600 msec. In order to investigate the changes of the background noise as a function of the number of samples being averaged with and without the presence of time-locked responses, a preceding baseline measure of the spontaneous EEG activity was also recorded. The baseline measure also had 1024 points and observed the brain's background activity over a period of 1024 msec (1 msec per point). The baseline sampling stopped immediately before the onset of the cue signal.

2.2.4. Procedures

1) *Practice session* Each subject started off with a practice session, the purpose of which was to help them understand what they were going to do. Subjects were seated in a chair in front of the LED box in a darkened room. They were instructed to press the appropriate lever after the test stimulus disappeared, i.e., if a subject was responding to the position of the longer line he would press the lever on the side on which the longer line had appeared in the discriminative stimulus. Having achieved a criterion of ten consecutive correct responses, subjects moved on to next session of inspection time estimation.

2) *IT session* A computer program using the PEST procedure (Taylor & Creelman, 1967) was used to control the process (see Section 1.3.1 for the description of the PEST procedure). Subjects were told to respond to a presented stimulus in the same way as in the practice session. They were also told that the duration of the stimulus exposure would vary according to their progress, and that if they could not detect the side on which the line had appeared, they were to guess. In this pilot study, inspection time was defined as the minimum stimulus exposure duration required to make 90% correct responses.

3) *Electrode placement* After session 2, electrodes were affixed to the scalp of the subject at the positions described earlier. The inter-electrode resistances were observed before and after the recording of ERPs. They were

all below 9.00 Kohms and reasonably balanced. The average resistance was 4.60 Kohms (S.D.=2.34).

4) *ERP session* This took place in the same darkened room and involved the same task. 215 ERP observations were collected coincident with the presentation of the subject's IT-type stimulus. A baseline measure preceding each ERP observation was also taken. This lasted for 1024 msec and stopped immediately before the onset of the cue signal. This session lasted for roughly 20 minutes. The whole experiment took about one hour and a quarter to complete.

2.3. Results and discussion

2.3.1. Assessing the disturbance from the mains

As the raw ERP data were collected without being screened through the 50Hz filter of the PA-300 amplifier, there might have existed in these recorded raw ERPs a 50Hz component representing the mains interference. Spectral analysis (BMDP1T, Dixon, 1983) was performed on the averaged response across the 215 samples of each subject. The results are shown in Fig. 2.1. The outcome presented in the left column of Fig. 2.1 was from the pre-filtered or raw AEPs, whereas the outcome in the right column resulted from the post-filtered or 'cooked' AEPs. The filtering was carried out by a computer program, which was based on moving average technique (Chatfield, 1980). The computer filtering program (in Fortran 77) was as follows:

```
      DO 1 I=1,204
      IB=(I-1)*5+1
      IS=IB+4
      TEMP=0.0
      DO 11 J=IB,IS
11    TEMP=TEMP+DATA(J)
1     ADATA(I)=TEMP/5.0
C
      DO 2 I=1,204
      IB=I
      IS=I+3
      IF (IS.GE.204) IS=204
      TEMP=0.0
      SN=0.0
      DO 21 J=IB,IS
      SN=SN+1.0
21    TEMP=TEMP+ADATA(J)
2     ADATA(I)=TEMP/SN
      DO 3 I=1,201
      TEMP=0.0
      DO 31 J=I,I+3
31    TEMP=TEMP+ADATA(J)
3     SDATA(I)=TEMP/4.0
```

The first step of the program is to take the mean of every five consecutive data points. Instead of the original sampling rate of 1000 cycles per second, thus, the sampling rate after this step become 200 cycles per second. By so doing, we may expect some frequency distortion to be removed (Picton & Hink, 1974). The second and the third steps of the program overcome the problem of the 50Hz disturbance from the mains. To do so, they smooth over any four consecutive data points along the trace coming out from the first step (Chatfield, 1980). As can been seen in Fig 2.1, the changes were dramatic. The obvious contribution of those frequencies around 50 cycles per second in the spectrum of the AEPs before filtering disappeared almost completely after filtering. The outcome given in Fig. 2.1, thus, not only demonstrated the existence of the disturbance from the 50Hz mains in our ERP recording environment, but also indicated that the computer filtering program was effective in removing the disturbance from the obtained AEPs.

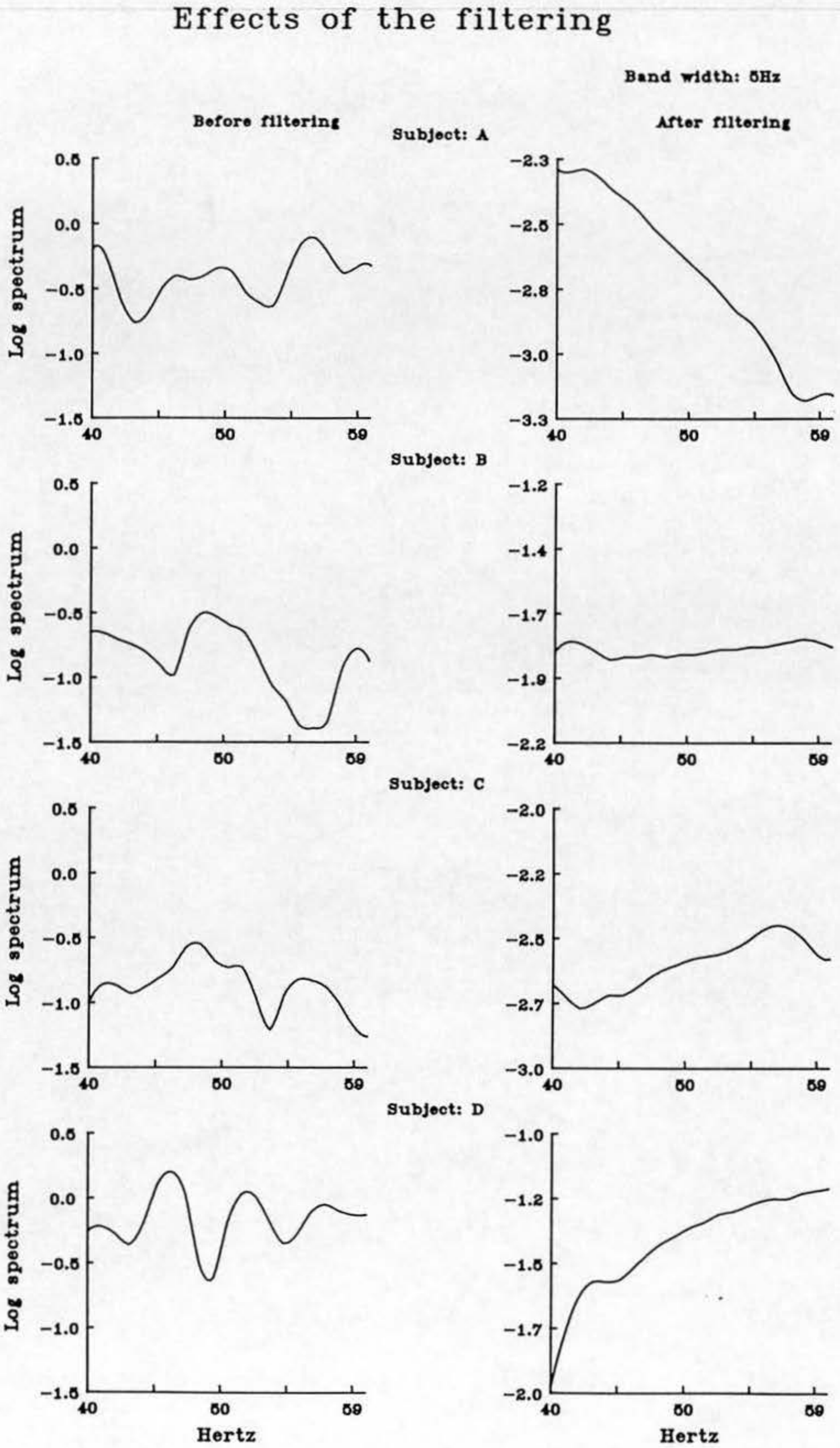

Fig. 2.1 Averaged traces were assessed by spectral analysis to observe the 50Hz disturbance before and after filtering process.

2.3.2. Effect of sample number on residual noise

Fig. 2.2 shows the mean standard deviations of residual waveform estimated by the +/- reference (Schimmel, 1967) as a function of the number of ERP samples to be averaged. In comparison with the variance of the residual waveform, plotting the standard deviation gave more distinct patterns when the value of the standard deviation was less than 1. To be consistent with the studies by others (Wong & Bickford, 1980; Don *et al.* 1984; Mason, 1984), the standard deviations presented here were calculated from the mean across the whole epoch, rather than a mean of zero (Vaughan, 1974).

Standard deviations of the residual waveform, also estimated by the +/- reference, for the baseline period are plotted in Fig. 2.3. As these baseline recordings were taken before the onset of the cue signal, they were more likely to have reflected the spontaneous EEG activity of the brain. Thus, it offered us an opportunity to compare the changing trends and amounts of the residual of background noise under the two conditions with and without the presence of the time-locked responses. The residual of background noise, as shown in Fig. 2.2 and Fig. 2.3, approximated to a horizontal line as the number of samples being averaged increased above 180. From the standpoint of economy, it appeared that there was no reason to have more than 180 samples for each average in the present ERP investigation. It was interesting to note that these converged lines varied within a small range and the range was slightly smaller when the time-locked component (ERP) was present (Fig. 2.2) than when it was absent (Fig. 2.3). This might imply that some sort of interaction between evoked potentials and spontaneous EEG activities had taken place. Perhaps, with time-locked signals the four subjects' brain activity might have been more standardized. Also, the amount of residual noise below that range was almost the same for both conditions with and without the time-locked components, and might have indexed the amount of noise caused by the external environment.

Fig. 2.4 gives the corresponding P value for the AEP data calculated by using equation (2). It seems the P value was not an acceptable indicator for our purpose, as it was too sensitive to approximate to a constant level. A small oscillation in Var(noise) could cause a big deflection (also see Don *et al.* 1984).

2.3.3. Defining a reference AEP

By inspecting Fig. 2.2 and Fig. 2.3, it was decided that 190 was the ideal number of a population of ERP samples for this particular investigation, since further sampling appeared to be redundant with respect to improving further the ratio of signal to noise. The first 190 samples were then averaged to get a mean response for each subject. As this mean response was derived from an ERP population with the ideal number of samples of a subject, it was therefore named reference AEP, or AEP_{ref}.

2.3.4. Finding a realistic N for averaging

The number of 190 as a criterion for collecting samples in the future experiments was close to being ideal from the point of view of eliminating noise from the AEP. However, it did not seem to be feasible to collect so many recordings in real experimental situations. If there are three eliciting conditions in an experiment and we want to compare the AEPs obtained under these conditions, for instance, the grand total of samples that have to be recorded from one subject would increase to 570. To collect so many samples within a run means that the recording period would have to be prolonged to nearly one hour. If subjects are retained in a darkened room for this length of time while performing a repetitive task, it is likely that their ERPs (and

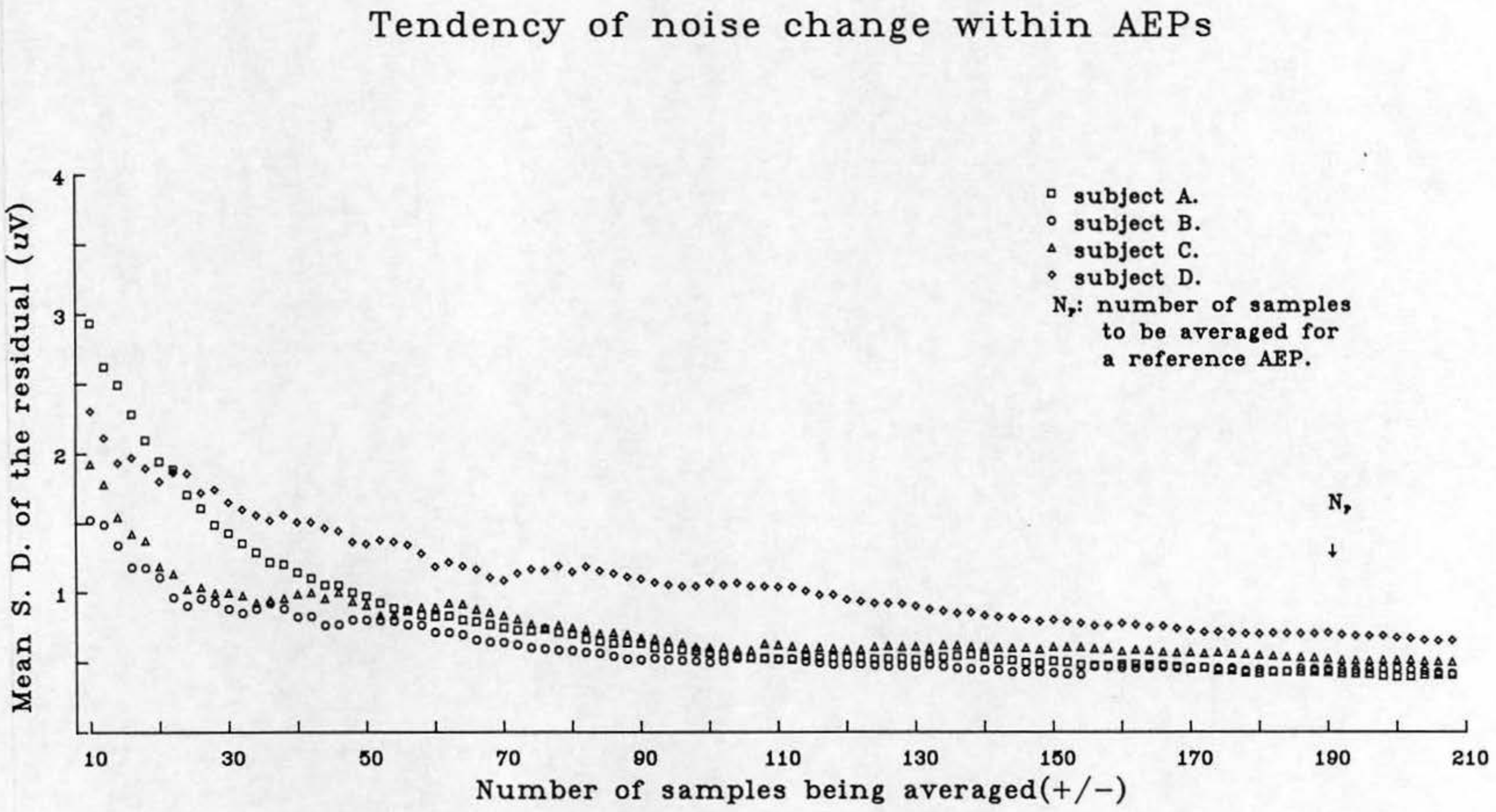

Fig. 2.2 Standard deviation of residual waveform estimated by +/−reference and plotted accumulatively every two samples.

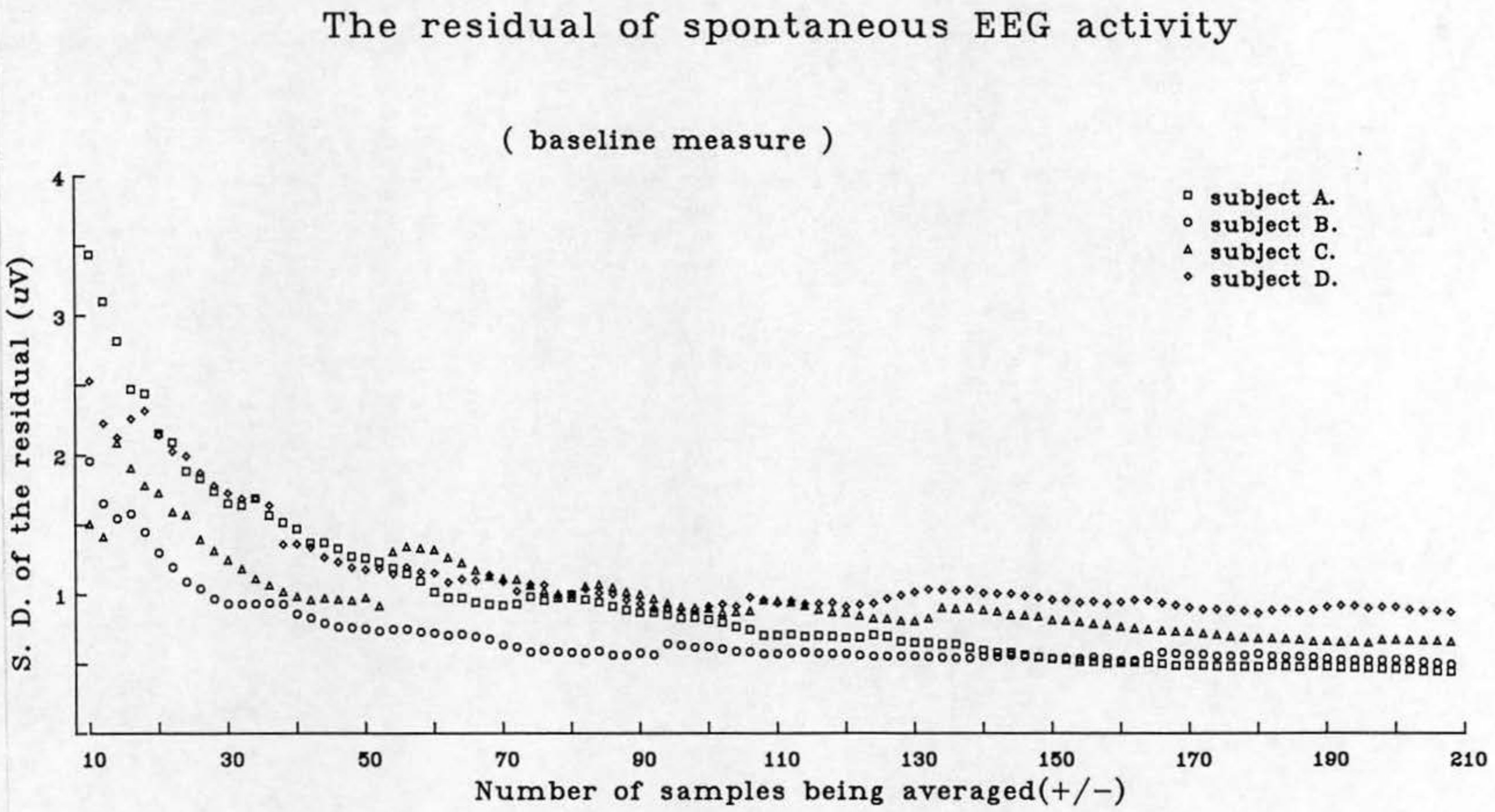

Fig. 2.3 Standard deviation of EEG residual activity estimated by +/−reference and plotted accumulatively every two samples.

P value = Var(AEP)/Var(+/-)

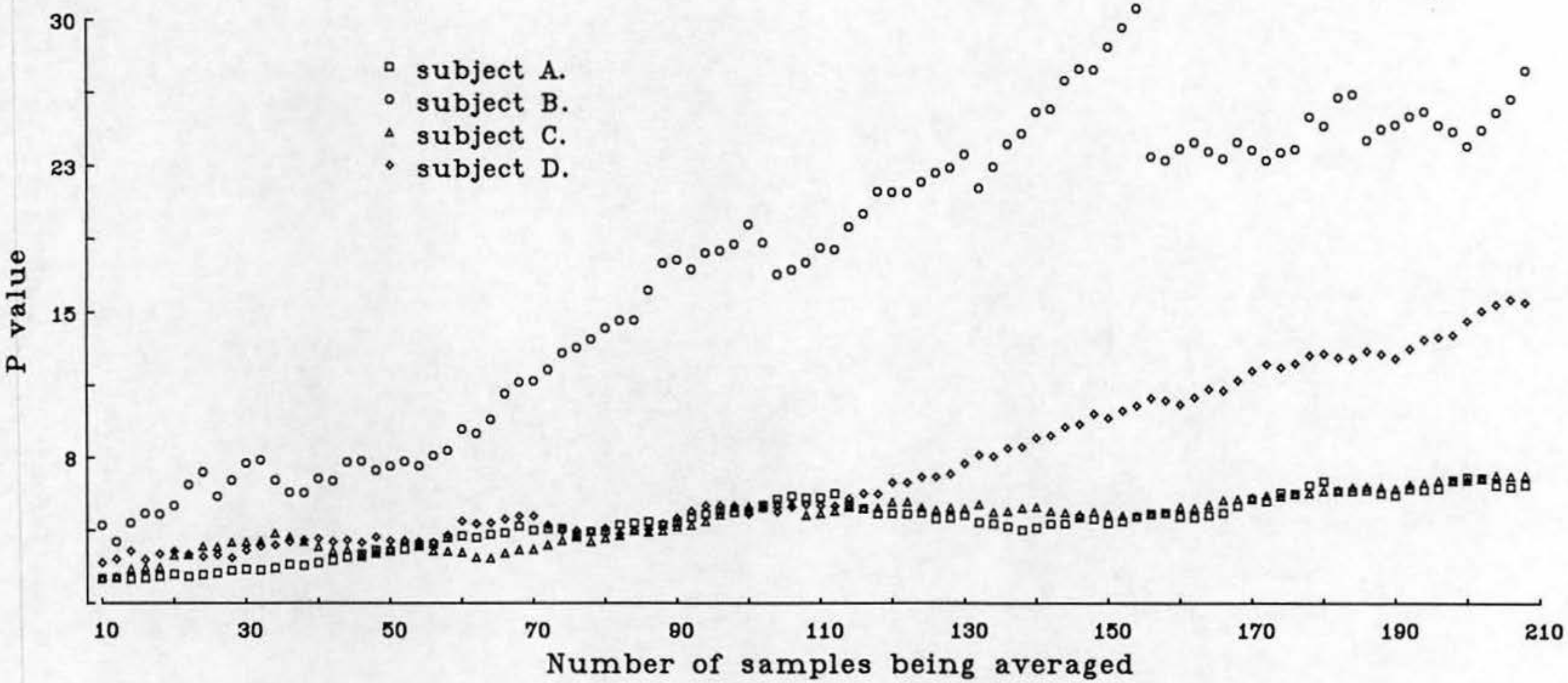

Fig. 2.4 P value calculated and plotted accumulatively every two samples.

therefore the experiment) will suffer (Uttal, 1965; Ritter *et al.* 1968; Donald, 1976, 1979; Picton *et al.* 1976). This problem has to be overcome before the investigation can go any further.

One way of getting around the problem is to examine the correlation of an AEP based on less than 190 samples with its AEP_{ref}. As shown in Fig. 2.5, the correlation coefficients of such AEPs with their AEP_{ref} were calculated and plotted cumulatively every four samples for each subject. A correlation coefficient of 0.75 was then defined as a criterion for the N selection. After inspection of the data, 64 was chosen as the minimum number for each average of ERPs (e.g. in Exp. 1, 2 and 6).[2]

In order to give the visual impression of how well a averaged response derived from 64 samples of ERPs can portray its reference, Fig. 2.6 shows comparisons between the AEP_{64}, its AEP_{ref} and their corresponding residual waveforms. The figure shows that the ratio of the signal amplitude of the AEP_{64} to the amplitude of its residual noise was, on average, greater than 2, a criterion commonly adopted in ERP investigations (Picton & Hink, 1974). Although subject D had a relatively large amount of residual noise (Fig. 2.2 and 2.3), his AEPs' correlations with the AEP_{ref} were not impaired (Fig. 2.5 and Table 2.1). This indicated that the time-locked components were at least partially independent of background EEG oscillations, which is a crucial assumption of the application of the averaging technique.

To determine whether or not a sample number of 64 would satisfy the

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[2] It may be worth pointing out that, in view of the fact that some studies derive AEPs from as few as 20 ERP samples, the number 64 as criterion for each average is perfectly acceptable for most AEP investigations (Fitgerald & Picton, 1984; Halliday *et al.* 1984; Campbell, 1985).

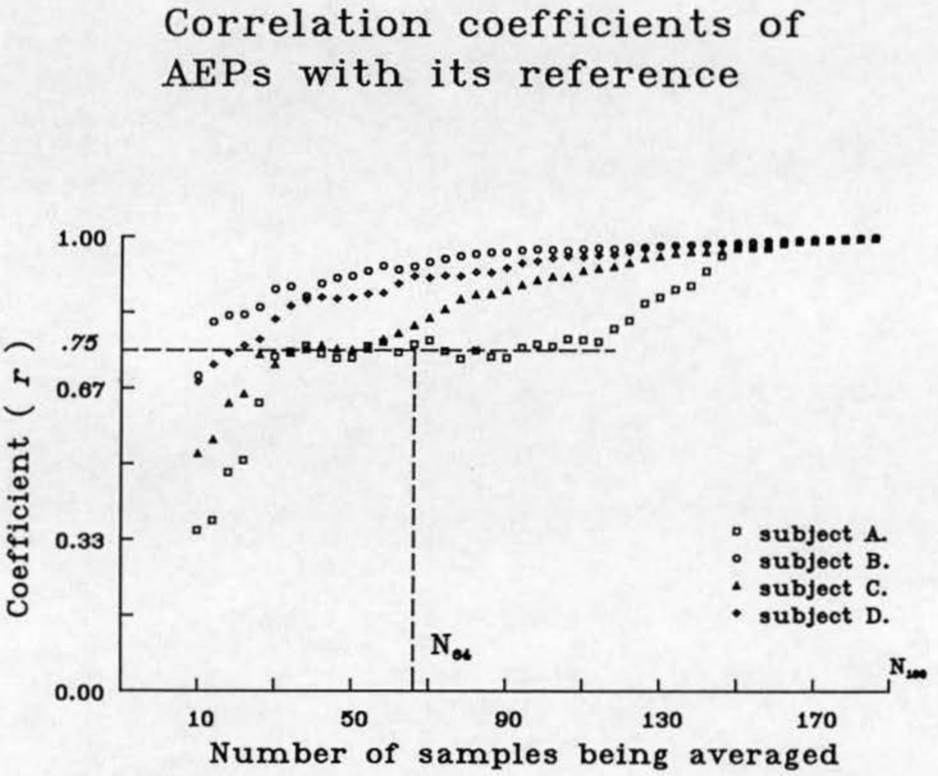


Fig. 2.5
Correlation coefficients of AEPs with its AEP_{ref}, calculated and plotted accumulatively every four samples.

Comparison of AEP_{64} with its AEP_{ref}

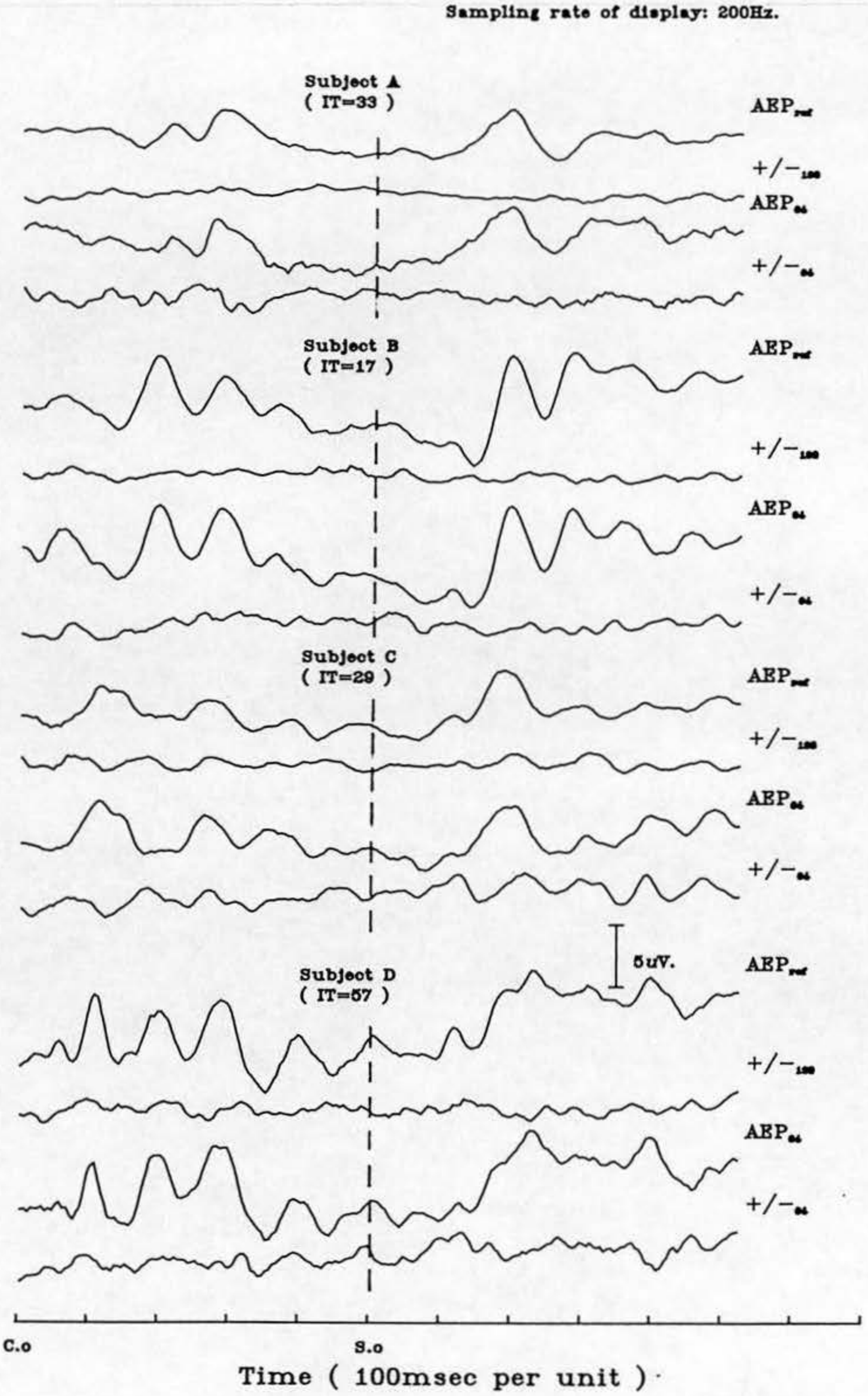


Fig. 2.6 AEP_{64} , AEP_{ref} , and their corresponding residual waveforms. Positivity upwards.

criterion of producing a correlation coefficient of 0.75 with its reference AEP, AEP waveforms resulting from different sets of 64 samples were correlated with their AEP_{ref} for each subject. The results are shown in Table 2.1. It can be seen that the figures of each subject concentrated within a small range, and all of them were around or over 0.75. A weighted *r* was calculated for each group using identical weights of 1 (Zar, 1984). The value of AEP_w was excluded from the calculation, because the number of samples being averaged for AEP_w was much less than 64. In general, the 0.75 criterion has been met.

2.3.5. Reproducibility and similarity of AEPs

It may be interesting to know the reproducibility of the AEP_{64}. Table 2.2 contains the lists of correlation coefficients between two AEPs resulting from entirely different groups of samples. As may be expected, the 0.75 coefficient criterion was not met across all subjects this time. On the other hand, the figures for AEP_{95} showed that by collecting more than 90 samples for each average could be more rewarding; but this would be at the expense of a 50% increase in duration of ERP recording (e.g. in Exp. 3 and 5).

Coming to the similarity between AEPs yielded by different types of stimuli (i.e. long line on the left, or on the right), the situation appeared to be similar to that of the reproducibility of an AEP (Table 2.3). A comparison of the coefficients in Tables 2.2 and 2.3 suggested that the AEPs elicited by the two stimulus patterns were almost as similar as those derived from ERPs without regard to the patterns of eliciting stimuli (also see Table 2.1). Thus, it seemed unnecessary to analyse them separately in future experiments.

Table 2.1
Similarity between AEPs and their AEP$_{ref}$

	Correlation coefficients			
Subjects	A	B	C	D
AEP$_{F(64)}$	.75	.93	.80	.90
AEP$_{S(64)}$	.71	.96	.88	.91
AEP$_{O(64)}$	.77	.95	.84	.88
AEP$_{E(64)}$	.77	.96	.89	.93
AEP$_{LC(64)}$	.71	.96	.87	.90
AEP$_{RC(64)}$	.81	.95	.87	.93
AEP$_{BC(64)}$	.75	.94	.83	.96
AEP$_{w}$		.92	.79	.92
weighted r	.75	.95	.85	.91

AEP$_{F(N)}$: average of first N samples.
AEP$_{S(N)}$: average of second N samples.
AEP$_{O(N)}$: average of first N samples with an odd number.
AEP$_{E(N)}$: average of first N samples with an even number.
AEP$_{LC(N)}$: average of first N samples elicited by stimuli with the long line on the left and with a correct response.
AEP$_{RC(N)}$: average of first N samples elicited by stimuli with the long line on the right and with a correct response.
AEP$_{BC(N)}$: average of first N samples with a correct response.
AEP$_{w}$: average of samples with wrong response.

Table 2.2
Reproducibility of an AEP

	correlation coefficients			
Subjects	A	B	C	D
$AEP_{O(64)}-AEP_{E(64)}$	.65	.92	.68	.75
$AEP_{O(95)}-AEP_{E(95)}$	.91	.98	.93	.85

$AEP_{O(N)}$: average of first N samples with an odd number
$AEP_{E(N)}$: average of first N samples with an even number

Table 2.3
Similarity between AEPs yielded by different patterns

	correlation coefficients			
Subjects	A	B	C	D
$AEP_{L(64)}-AEP_{R(64)}$	.62	.90	.67	.77
$AEP_{L(95)}-AEP_{R(95)}$	.71	.91	.78	.80

$AEP_{L(N)}$: average of first N samples to the stimuli with the long line on the left.
$AEP_{R(N)}$: average of first N samples to the stimuli with the long line on the right.

2.3.6. Mean standard deviation of the AEP_{64}

As it was decided to use 64 samples as the minimum for each mean response, it would be useful for tests of significance to know the standard deviation of the AEP_{64}. The standard deviation of the AEP_{64} was in fact the standard error of the group of 64 ERP samples. To estimate theoretically the standard error of the group of 64 ERP samples, the $N^{1/2}$ rule was applied to the average of the mean standard deviations of the four subjects' AEP_{ref}. By so doing, a theoretical curve of the standard error over the sampling epoch of a group of ERPs was obtained (Fig. 2.7). Because it was based on the results of the four subjects the standard error in Fig. 2.7 was a 'mean' standard error. As can been seen, the group of 64 ERP samples had a mean standard error of about 1.00 μV. In other words, the mean standard deviation of the AEP_{64} was about 1.00 μV.

2.3.7. AEP components observed in IT paradigm

A brief visual inspection of Fig. 2.6 indicates that the most conspicuous component of the AEP obtained under the condition of subjects' performing the inspection time task was a positive deflection peaking at about 200 msec from stimulus onset, i.e., the P200 component. Furthermore, the shape of the P200 appeared to have a relationship to the corresponding stimulus exposure duration (IT estimate). It appeared that the shorter the IT estimate was, the steeper was the slope of the N150-P200 complex. Obviously, this was a valuable clue for future experiments. Although a positive peak with a latency of about 300 msec (P300 component) could also be detected, it was not distinct for every subject (Simson *et al.* 1977).

To examine these components further, principal components analysis (PCA) was employed here. In order to have as many AEPs as possible to put into the analysis in the present situation, for each subject every 16 consecutive samples was averaged; this gave 13 traces of AEP_{16} for each subject. The total number of AEP traces from four subjects was thus 52. These averaged traces, which had an epoch of 500 msec and began from stimulus onset, were further smoothed to contain 50 time points or variables. The PCA with varimax rotation (BMDP4M, Dixon, 1983) was thus performed on a data base of

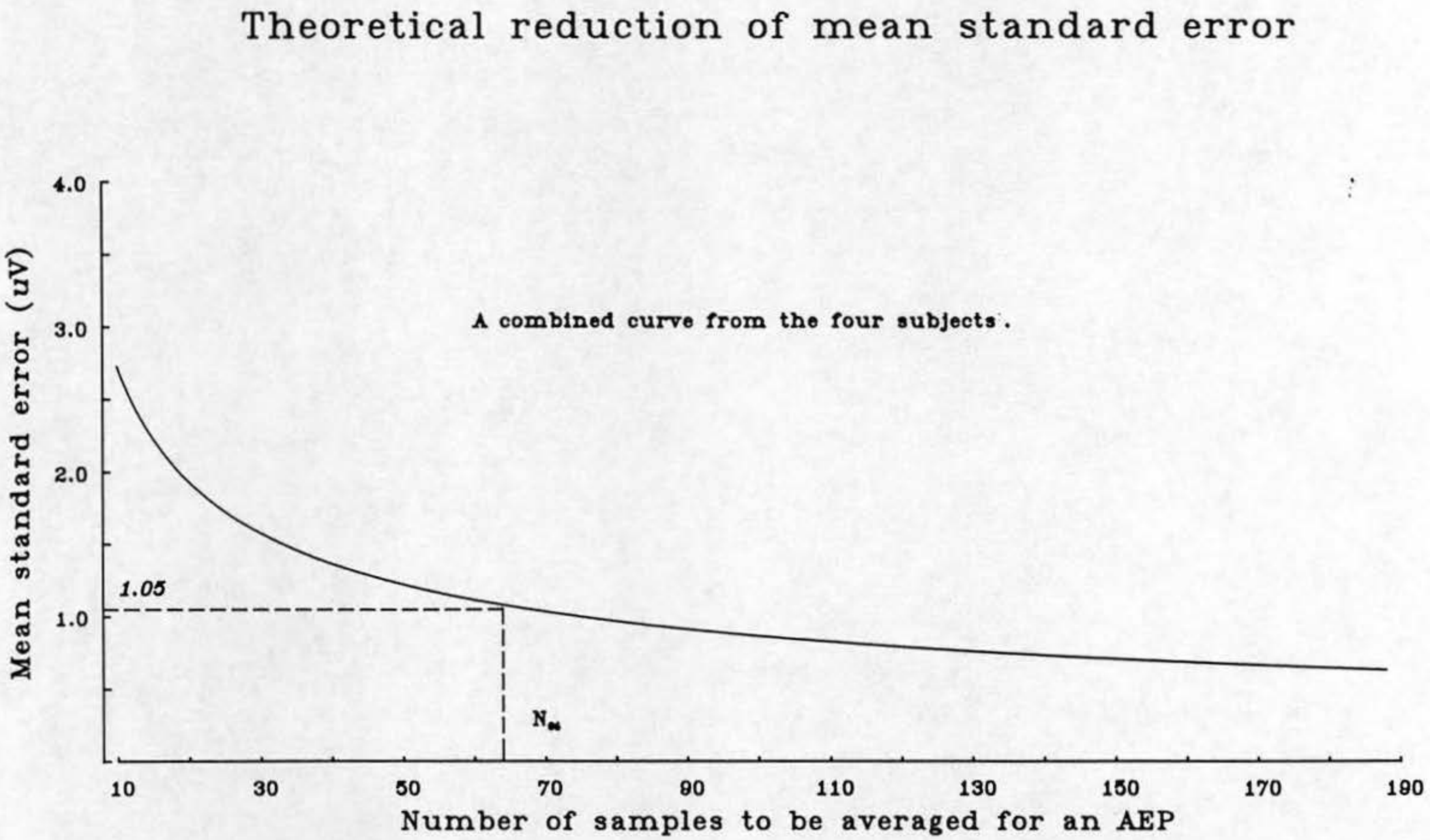


Fig. 2.7 Theoretical reduction of mean standard error for a group of ERPs based on the mean S. D. of AEP_{ref}.

52 waveforms by 50 time points. Although this analysis had rather few cases for the number of variables, it was important in this pilot study to observe to what extent the AEP components picked out by eye could be objectively confirmed by the PCA technique (John *et al.* 1973; Donchin & Heffley, 1978; Picton & Stuss, 1980; Friedman *et al.* 1980).

In interpreting the results obtained through this PCA exercise, it must be remembered that when extracting common factors from the AEP data base the eigenvalue in this analysis was defined at 3.00, rather than 1.00 (Picton & Stuss, 1980). One reason for this was that any component of AEP exists only within a plane. In other words, a factorial component of AEP consists of at least two vectors (i.e. two time points). The total variance of any single vector, or variable, prior to analysis is equal to eigenvalue of 1.00 (Kim, 1975). This means that in a PCA of AEP data the eigenvalue for extracting common factors should be greater than, or at least equal to, 2.00. The other reason was that when the analysis was under way, it was found that an eigenvalue set at 3.00 resulted in four factorial components, which were sufficient to represent all the components visually identifiable in the AEPs (Fig. 2.6). For the simplicity of interpretation and presentation, it was then decided to use that value for the analysis.

The correlation matrix was factor analysed, which revealed four common factors that had explained 79% variance in the data space. The covariance matrix with varimax rotation was used to extract four factors (Donchin & Heffley, 1978; Friedman *et al.* 1980). These factors are presented in Fig. 2.8.

As expected, the first factor, which peaked in latency at about 190 msec, was identified with the P200 component. Factor 2 was most highly correlated with time points in the 300-350 msec portion of the response and was

AEPs' components
generated by factorial analysis

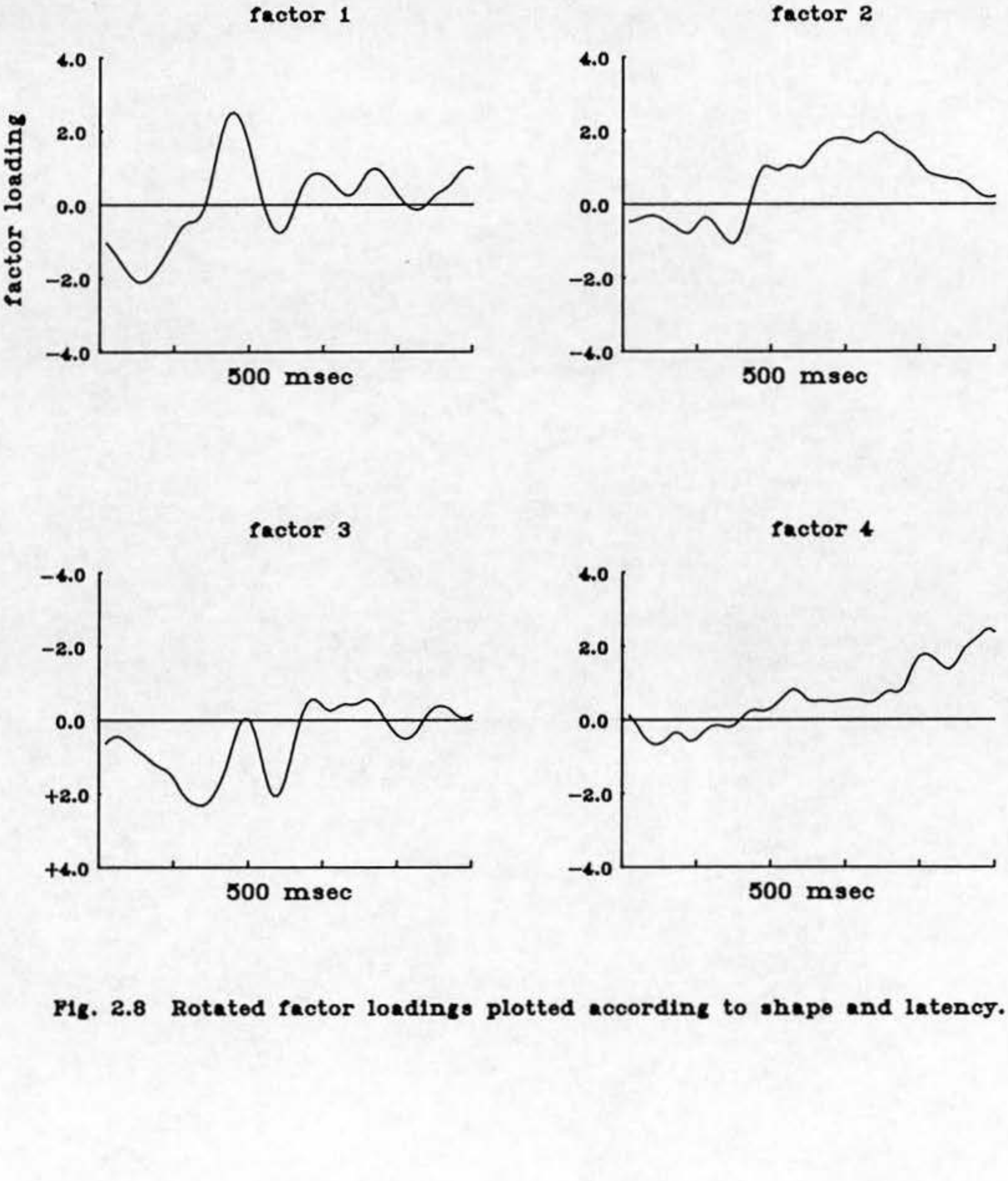


Fig. 2.8 Rotated factor loadings plotted according to shape and latency.

identified with the P300 component. Factor 3, which peaked at 150 msec, was associated with a negative deflection with a latency of 150 msec (i.e. N150 component). The fourth factor that occupied the rather later portion of the epoch looked as if it might have been an overall recovery from the preceding CNV activity (Roth, 1977; Friedman *et al.* 1980).

2.4. Summary

The pilot investigation has achieved several things. First, the interference from the mains has been revealed; it can be overcome by using the programmed filter. Second, 64 has been defined as the absolute minimum number of samples required for each reliable average (e.g. in Exp. 1, 2, and 6). Taking into account limits on experimental duration, if it is possible to collect more samples during a run a number of samples around 90 is preferable for averaging (e.g. in Exp. 3, 4, and 5). Third, the most distinctive component of the AEP observed under the condition of subjects' performing the inspection time task is the P200. Two other less distinctive components are the P300 and N150.

CHAPTER 3

A BRIEF REVIEW OF P200 AND P300 COMPONENTS

In chapter 1, the IT measure is described as a function of the rate at which sensory information in iconic storage or in the sensory register is encoded, or transferred, into short-term memory (STM) (see Section 1.4.1), and one of the goals of this study is to try to link the IT measure to AEP components. The idea behind this is obvious: if such components do exist, variations in their latency or form may reflect individual differences in the speed of information transmission from the sensory register to STM, within which the encoded information is processed with respect to task requirements (Hillyard & Woods, 1979). To find out which of the AEP components may be the most promising candidate in terms of indexing this stage of information processing, in this chapter I shall briefly review the characteristics of some AEP components in relation to the concerns of this study.

3.1. P300 and its psychological role

Brain potentials evoked during task-oriented paradigms usually consist of several components (Hillyard *et al.* 1973; Rohrbaugh *et al.* 1974; Squires, N.K. *et al.* 1975; Stuss & Picton, 1978; Picton & Stuss, 1980; Donchin, 1981; Loveless, 1983; Empson, 1986). Among these, the P300 component has attracted most research (Tueting *et al.* 1971; Courchesne *et al.* 1975; Donchin, 1981; Pritchard, 1981). The role of the P300 component in terms of information processing is not established; proposals must take account of its sensitivity to the frequency (Squires, N.K. *et al.* 1975) and the task relevance of stimuli (Ritter & Vaughan, 1969; Squires, K.C. *et al.* 1977); and include controlled processing of the information delivered by an event (Rosler, 1980), context updating of a cognitive model (Aleksandov & Maksimova, 1981), and subjective categorization of events (McCarthy & Donchin, 1981; Donchin, 1984). Details on the P300 component can be found in an excellent review by Pritchard (1981).

However, it seems evident that the characteristics of the P300 component observed under experimental conditions do not satisfy the requirement of being a cortical correlate of the process of encoding sensory information from iconic storage into STM. For instance, it is well-known that distinct P300 component can occur under conditions where external stimuli or events are absent (Sutton *et al.* 1967; Picton & Hillyard, 1974; Ruchkin *et al.* 1980a). That external events are not necessarily needed for generating the P300 rules out the possibility that this component by itself is a cortical indicator of the encoding of sensory information into STM.

On the other hand, the P300 component appears to indicate the termination of the process of evaluation (Adam & Collins, 1978). In a study of the P300, McCarthy & Donchin (1981) asked their subjects to identify which of two target words (RIGHT or LEFT) was embedded in a matrix of characters exposed briefly on a cathode-ray tube. Four types of matrices were used. In 'noise' matrices, the background positions were filled with randomly chosen alphabetic characters (targets had low discriminability). In the 'no noise' matrices, these positions were filled with the # symbol (targets had high discriminability). Subjects indicated the identity of the target word by pressing one of the two response buttons. If the presentation of the target was preceded by the cue SAME, the right button was the appropriate response for the target RIGHT, and the left button was correct for LEFT (compatible response). If the presentation of the target was preceded by the cue

OPPOSITE, the right button was now appropriate for LEFT, and the left button for RIGHT (incompatible response). The hypothesis was that processes concerned with the categorization of stimuli would affect P300 latency and reaction time (i.e. a longer P300 latency and longer reaction time for 'noise' trials than for 'no noise' trials), and that processes of response selection and execution would have no effect upon P300 latency (i.e. similar P300 latencies for both compatible and incompatible responses under each of the two conditions of stimulus discriminability). It was found that the mean P300 latency for the 'no noise' trials was 589 msec for the compatible response and was 617 msec for the incompatible response. For the 'noise' trials, these values were 792 msec and 796 msec. The P300 latency difference of 191 msec due to the discriminability factor was statistically significant ($p<.001$). The 16 msec difference associated with the stimulus-response compatibility factor was not statistically significant ($p<.228$). The data thus confirmed their proposition that P300 latency is sensitive to the duration of stimulus evaluation processes. They asserted that the process is contingent on stimulus categorization.

Suppose that what McCarthy & Donchin found is true. It leads us to the speculation that the process of encoding sensory information from iconic storage into STM must take place before any evaluation of the encoded information can be carried out. The rationale is very straightforward. It is impossible to analyse the information until it has been available in STM. If there exists an AEP component which reflects that encoding process, it must manifest itself before the occurrence of the P300 component.

3.2. P200 and its characteristics

In the pilot study (see Section 2.3), there was a distinct P200 component (or N150-P200 complex) in subjects' AEP waveforms when performing the IT task. Indeed, researchers agree unanimously that the N150-P200 complex of AEPs recorded at the vertex is similar in all modalities and may reflect similar neural and/or psychological operations (Picton & Hink, 1974; Allison *et al.* 1977; Van Voorhis & Hillyard, 1977; Goff *et al.* 1978; Hillyard & Woods, 1979).

In the literature, the P200 appears to have a remarkable feature. It occurs distinctively when an eliciting stimulus is present, and its amplitude decreases dramatically to such an extent that it appears sometimes to be *negative* when the external stimulus is absent (Picton & Hillyard, 1974). Klinke *et al.* (1968) reported a study in which subjects were advised to keep as alert as possible and to direct attention to the stimuli provided. Stimuli were pulses of sinusoidal vibration (200 cycles per second) which were applied to subjects' finger-tips at the rate of 1.163 pulses per second. Each pulse was 40 msec in duration determined at 50% of maximum amplitude. The intensity was 60dB above threshold. Evoked potentials were recorded in a bipolar fashion with one electrode at the vertex and the other in the middle meatus of the left side of the nose. Single pulses of the stimulus sequence were omitted irregularly at intervals ranging from 6-20 seconds. The response to the pulse before the omission, to the omission of a pulse and to the pulse immediately following was observed and analysed. Additionally, the activity from electrodes placed over the posterior neck muscle and at the lateral margins of both orbits, as well as the upper and lower margins of one orbit (both were alternatively tested), was summated in order to check whether omitted stimuli elicited muscle activity or eye movement. They reported: "The average response evoked by vibratory pulses to the finger-tips and recorded from vertex versus middle nasal meatus was of similar wave form to the auditory evoked response. Its main components were a small initial positivity at 60-70 msec after stimulus onset followed by a negative double peak at 110-140 msec. The subsequent large positive wave with a latency of 200-230 msec rarely showed a distinct peak, but tended to form a plateau. After another small negative deflection the initial potential level was reached at approximately 500 msec. If a pulse of the stimulus sequence was omitted a typical cerebral response was consistently evoked, which was different in waveform and latency from the potential following the stimulus. After an early initial positivity, which was not always detectable in the random fluctuations of the potential, a small negative wave arose and reached its maximum 200-240msec after the time when the stimulus onset had been due. It was followed by a large positive wave (latency 340-370 msec) which again tended to form a plateau. The response to the pulse following the omission was of the same general wave form as ordinary pulse response." Barlow *et al.* (1965) reported a similar observation. They obtained small responses to the omission of an expected light stimulus. These responses occurred with approximately the same latency as the response to the light stimuli, but they were of opposite polarity.

Armington (1981) studied cortical evoked potentials time-locked to eye-blinks, or stimulus transients. He found that the visually evoked cortical potentials elicited by the light transients that accompany blinking and recorded from the occipital region (O_z) appeared to have two sections. The first was an initial series of fluctuations that followed the blink onset after a short delay. Its most prominent feature was a positive peak that appeared at high luminances with a delay of about 85 msec. The second section appeared after the blink had ended. It had an initial small positive wave that gave way to a large negative deflection peaking 225 msec after the onset of the blink.

Other studies report that when subjects are asleep, the P200 component of auditory AEPs decreases in amplitude and increases in latency (Picton *et al.* 1974). Fruhstorfer and Bergstorm (1969) found that the vertex response (N150-P200 complex) to a click stimulus was large and stable when subjects were in an alert state. With decreasing vigilance, a progressive amplitude reduction of the vertex potential was observed. When subjects were almost asleep, these components to the click had approximately 25% of their original size at the alert stage.

These findings imply that stopping the supply of sensory information (i.e. omission of a stimulus) to the brain will diminish the amplitude of the P200 component, and that when the brain is not in its normal working state the P200 component will not be generated. Suppose that, when the supply of sensory information is stopped, the process of encoding sensory information has nothing to work with. This characteristic of the P200 component could mean that the active state of encoding mechanism might be responsible for the increase in amplitude of the P200 component. As Picton and Hillyard (1974) put it, the N150-P200 complex may represent the activation of neural assemblies involved with analysis of incoming auditory information. Furthermore, the P200 component seems to show little variation in response to patterned light during manoeuvres likely to cause shifts in attention (Spehlmann, 1965).

In fact, the idea that the P200 component might index the process of encoding information from the sensory register into STM has been suggested in a study by Chapman *et al.* (1978). In their investigation of evoked potentials in a number and letter comparison task, two numbers and two letters were flashed individually in random order with an interval of 3/4 second preceded and followed by a blank flash. Subjects' task was to compare the two numbers on number-relevant runs, the letters being irrelevant to the task. In the other half of the experiment, the numbers were irrelevant and the task was to compare the two letters. For the first relevant stimulus in each trial, the information had to be stored by subjects until the second relevant stimulus occurred, after which the comparison could be made. ERP data were analysed using principle components analysis, and the authors found a factorial component with a poststimulus peak at about 250 msec was related to the storage of information in STM. This component tended to be positive for the stimuli whose information needed to be stored by subjects. Furthermore, its magnitude was more positive for the first of the two relevant stimuli presented on each trial than for the second relevant stimulus. The interpretation given was that this component may have reflected the process of reading information out of a sensory register into STM.

3.3. Measurements of AEP components

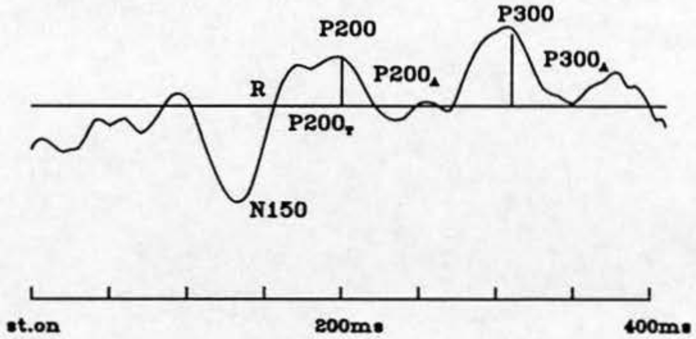
AEP components may be measured in various ways. The most commonly used measurements are latency and amplitude. Conventionally, the latency of a component is defined as the duration from stimulus onset to the point where the peak, or trough, of the measured component occurs. In relation to each individual the temporal reference (i.e. the onset of the stimulus) used in measuring latencies is externally fixed, rather than internally determined. Some have suggested that differences in skull structure, skin resistance, age of subjects, state of arousal and the like, might delay the occurrences of peaks or troughs of AEP components (Picton & Stuss, 1980; Barrett, 1985). To what extent the latency of a peak is affected because of this purported delay is unknown, but it may be different from one subject to another. Conventional latency measures do not take this possibility into account. If the latency is to be related to variables such as intelligence and inspection time, it is possible that these relationships, if they exist, may not be observed. For instance, delaying the occurrence of the N150 component will cause an increase of the latency of the following P200 component in the surface recorded waveform and, in turn, the delayed P200 component may push the peak of the P300 component away from the position where it may otherwise occur. If this effect varies from one subject to another, the measured latency of the P300, P200 and other components from stimulus onset may destroy any relationship that it has with other variables.

On the other hand, it was seen in my pilot study that subjects with faster inspection times had steeper slopes in the N150-P200 complex, and subjects with slow inspection times showed the opposite (see Fig. 2.6). To measure this phenomenon more accurately, we must examine the mean potential of a given portion of the AEP, which contains the N150-P200 complex, so that parameters closely relevant to the slope of the complex can be measured in relation to the mean potential. This method is illustrated diagrammatically in Fig. 3.1. In the top part of Fig. 3.1, the mean potential is calculated along the whole recording epoch, whereas in the bottom part, where only a small portion of that epoch is presented, the mean potential is calculated along that given portion, which is called window analysis. The reason for doing window analysis will be given in next chapter (Bentin *et al.* 1985).

As can be seen, the point where the AEP contour intersects with the mean potential is taken as a reference. From this a latency measure is calculated as the measured time from the reference point to the place where the following maximum peak occurs. As the peak to be measured is that of the P200, the

Illustration of AEP measures

(a) whole epoch analysis



(b) window analysis

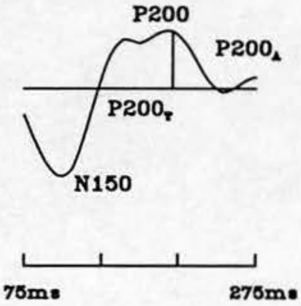


Fig. 3.1 Relevant parameters of AEP components to be used in this study. Positivity upwards. R: the reference. Horizontal line: mean potential.

parameter is then called 'time-to-develop P200', or the $P200_T$. Another measure is the amplitude of the measured peak (i.e. the $P200_A$) in relation to the mean potential. As this reference for measuring the latency of a peak is based on each individual subject, it might help us to avoid the problem mentioned above; at least, we can compare the results from this measurement with those taken by their conventional definitions.

3.4. Summary

In Chapter 1, it has been pointed out that the IT measure is assumed to index the process of encoding. The AEP data reviewed in this chapter seem to imply that the P200 component may reflect the process of encoding information from a sensory register into STM. Also, in the pilot study of Chapter 2 the P200 component did appear to be interesting under the concerns of the present study.

As to the measurement of AEP components, the relations between AEP latency measures and other variables might be affected by a potential flaw in the existing latency measurement. With this in mind, a new measure, called $P200_T$, is defined with the hope that it allows us to examine more accurately the relationship of the P200 component with both inspection time and intelligence.

CHAPTER 4

CORTICAL CORRELATES OF INSPECTION TIME

In this chapter, the results of two experiments will be reported. The aim of these experiments was to observe whether the form of the P200 component could be linked to subjects' IT estimates. As discussed above, the P200 component is thought to reflect the process of encoding (Chapman *et al.* 1978), and the inspection time is said to index the rate of sampling of sensory input in the initial stages of information processing (Vickers *et al.* 1972; Saccuzzo *et al.* 1979; Vernon, 1981). Since both measures are assumed to reflect the processes of encoding, it is of interest to examine their relationship at the beginning of this investigation proper.

In order to seek other factors which might also contribute to subjects' performance on the IT task, such as the evaluation of encoded information, the parameters of the P300 component were examined at the same time.

4.1. Experiment 1

In this experiment, an attempt was made to compare AEPs obtained using different conditions of eliciting stimuli and to explore the relations of the P200 and P300 components with the IT measure.

4.1.1. Methods

1) Subjects. Four male and four female university students ranging in age from 21 to 30 years (mean=24.1, S.D.=2.94) participated in this experiment. They had normal or corrected-to-normal vision.

2) Stimuli. Cue signal and test stimuli used in this experiment were the

same as described in the pilot study (see Section 2.2.2) (Diagram 2.1). Four subjects, two male and two female, were asked to press the lever on the side at which the longer vertical line had appeared in the discriminative stimulus. The others responded to the shorter vertical line. The presentation of the two types of stimuli (longer line on the left, or on the right) was randomized, and so was the post-response interval, which varied over the range of 2-3 seconds. (The post-response interval was the time elapsed after subjects' response and before the presentation of next cue signal.) Subjects were instructed not to perform the response until the test stimulus was off.

3) ERP data recording. The set-up of the PA-300 amplifier and the electrode placement was exactly the same as described in the pilot study (see Section 2.2.3). The computer sampling rate was 1 KHz with a sampling epoch of 1024 msec, starting from the cue onset. As was shown in the pilot study, 64 recordings was the minimum number acceptable for each average. In this experiment, 210 samples were collected within 20 minutes from each subject. These samples were elicited by stimuli of three types, randomly intermixed in the sequence, each type appearing 70 times. The eliciting stimulus of type 1 (IT) was the IT-type stimulus, that is, the discriminative stimulus was presented for a period equal to the subject's (previously estimated) inspection time, followed by the mask (Kirby & McConaghy, 1986). For type 2 (IT^+), the discriminative stimulus was presented for much longer (1.75 times the subject's inspection time) before the mask replaced it. For type 3 (IT^-), the discriminative stimulus was presented only briefly (0.25 times the subject's inspection time) before the mask came on. The overall presentation duration was the same for all test stimuli, i.e. 600 msec from the stimulus onset to the mask offset (Diagram 4.1). As in the pilot study, all stimuli were preceded by a 300 msec cue (a horizontal bar 18mm long at the centre of the LED array),

which started 500 msec before the stimulus onset (Diagram 2.1).

4) Procedure. As in the pilot study, subjects went through sessions of practice, inspection time estimation, electrode placement and ERP recording in that order. Subjects' inspection time was defined as the minimum stimulus exposure duration required for them to make 90% correct responses. In the ERP recording session, 210 observations were then collected with the presentation in a randomized sequence of the three types of eliciting stimuli (IT, IT^+ and IT^-), each of which occurred 70 times. The skin resistances were monitored before and after the recording. The average was 4.6 Kohms with the S.D. being 2.34.

5) Data analysis and measures. There was no subjective editing used in this experiment. Three average waveforms, corresponding to IT, IT^+ and IT^- respectively, were obtained from the first 64 recordings of each category for each subject. After averaging, these waveforms were smoothed using the filter described in Section 2.3.1.

The temporal measures of the AEP taken in this experiment included: the $P200_T$ which has been described earlier (see Section 3.3), the P200 latency ($P200_L$) and the P300 latency ($P300_L$). The $P200_L$ and $P300_L$ were defined conventionally. Two amplitude parameters were also measured; the amplitude of the P200 component ($P200_A$) and the amplitude of the P300 component ($P300_A$), both were relative to the mean potential. The P200 was defined as the maximum peak within the range of 150 msec to 250 msec from the stimulus onset, and the P300 was the maximum peak within the range of 250 msec to 400 msec.

In any analysis of the latency and amplitude of subjectively defined AEP

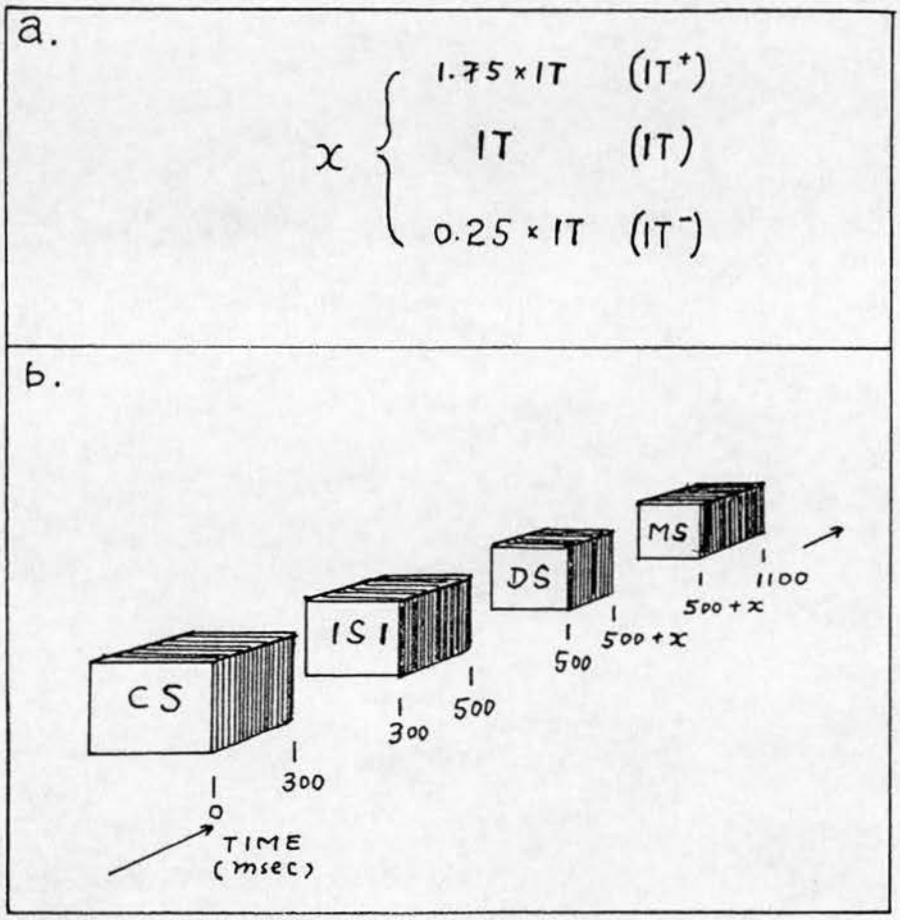


Diagram 4.1

Diagram 4.1a shows the exposure durations of the discriminative stimulus. Diagram 4.1b outlines the procedure. CS: cue signal; ISI: inter-stimulus interval; DS: discriminative stimulus; MS: backward mask.

peaks, the reliability with which these peaks can be measured is an issue. In this experiment, each AEP trace was scored on two occasions (separated by a week) for the $P200_L$, $P200_A$, and $P200_T$ parameters, by two independent judges. The test-retest and inter-observer reliability of the AEP measures was examined.

4.1.2. Results and discussion

Subjects' estimated inspection time scores ranged from 18 msec to 78 msec (mean=34.12, S.D.=20.64). Fig. 4.1 compares the filtered AEP waveforms for two subjects. Subject A had the longest IT score, and subject B the shortest. The waveforms of IT, IT^+ and IT^- for each subject were superimposed and can be seen in Fig. 4.2.

(1) *P300 component* We should expect to see a clear difference between AEPs to the IT^+ and IT^- types of stimuli in the region of the P300. In responding to the IT^+ stimulus, subjects were faced with a relatively easy discrimination between task-relevant stimuli (i.e. Long-Left or Long-Right), a situation in which a well developed P300 wave would be expected. By contrast, in IT^- trials the discriminative stimulus was presented so briefly (for as little as 4.5 msec to some subjects) that subjects were essentially guessing which stimulus had been presented. Under these conditions, the P300 was expected to be small or absent (Ritter & Vaughan, 1969; Hillyard, 1971; Kutas *et al.* 1977). The IT trials were of intermediate difficulty, and the P300 would be expected to be present, but the peak should not be as marked as in the easy IT^+ trials.

As can be seen in Fig. 4.2, the P300 amplitudes appeared to be different for different types of eliciting stimuli (Table 4.1). An one-way ANOVA for repeated measures indicated that these amplitude differences were statistically significant ($F(2,14)=5.492$, $p<.025$). From Table 4.1, it appeared that the

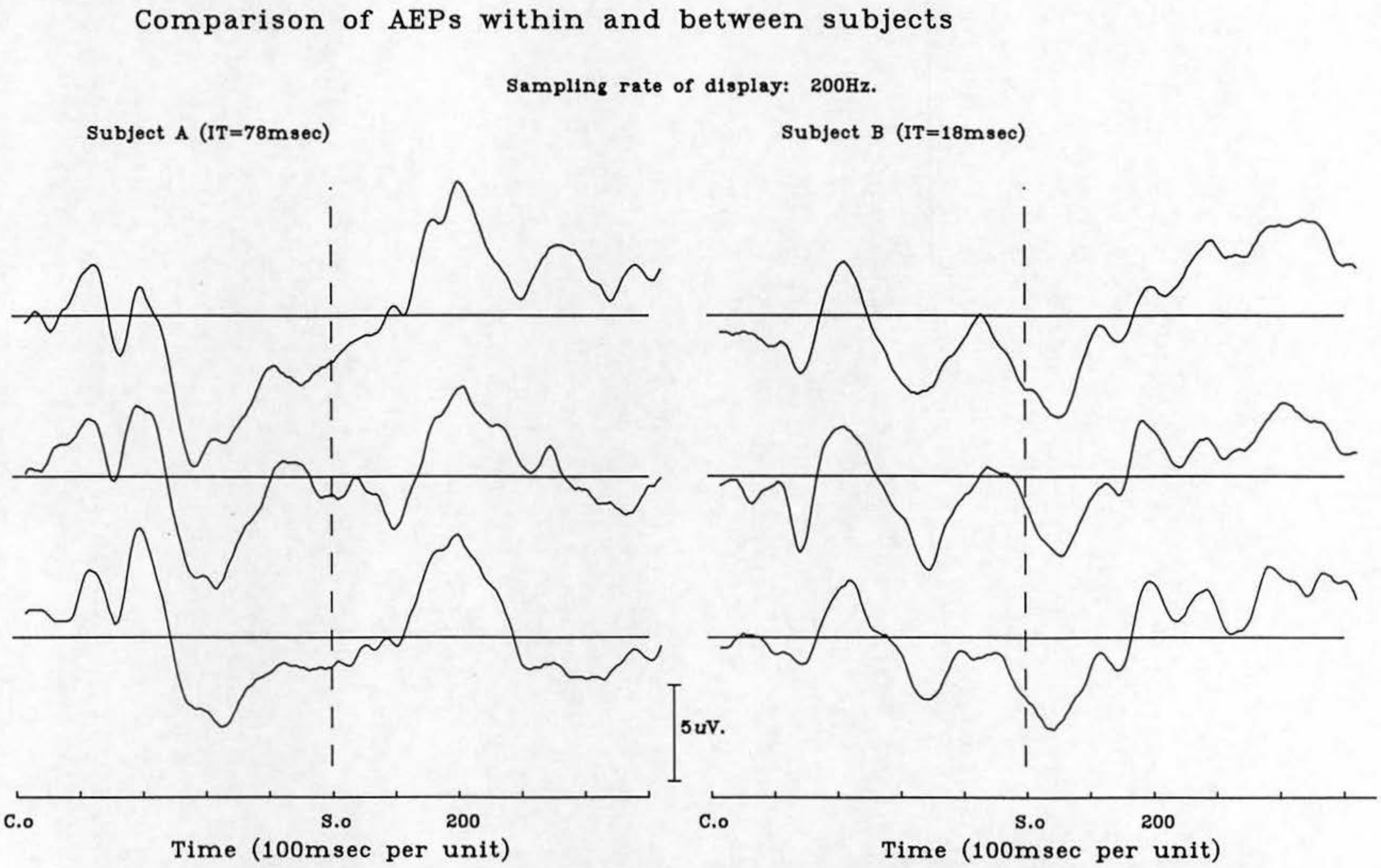


Fig. 4.1 Averaged EPs for two subjects. The top curve was corresponding to IT$^+$, the middle to IT, and the bottom to IT$^-$. Positivity upwards. Vertical line: stimulus onset.

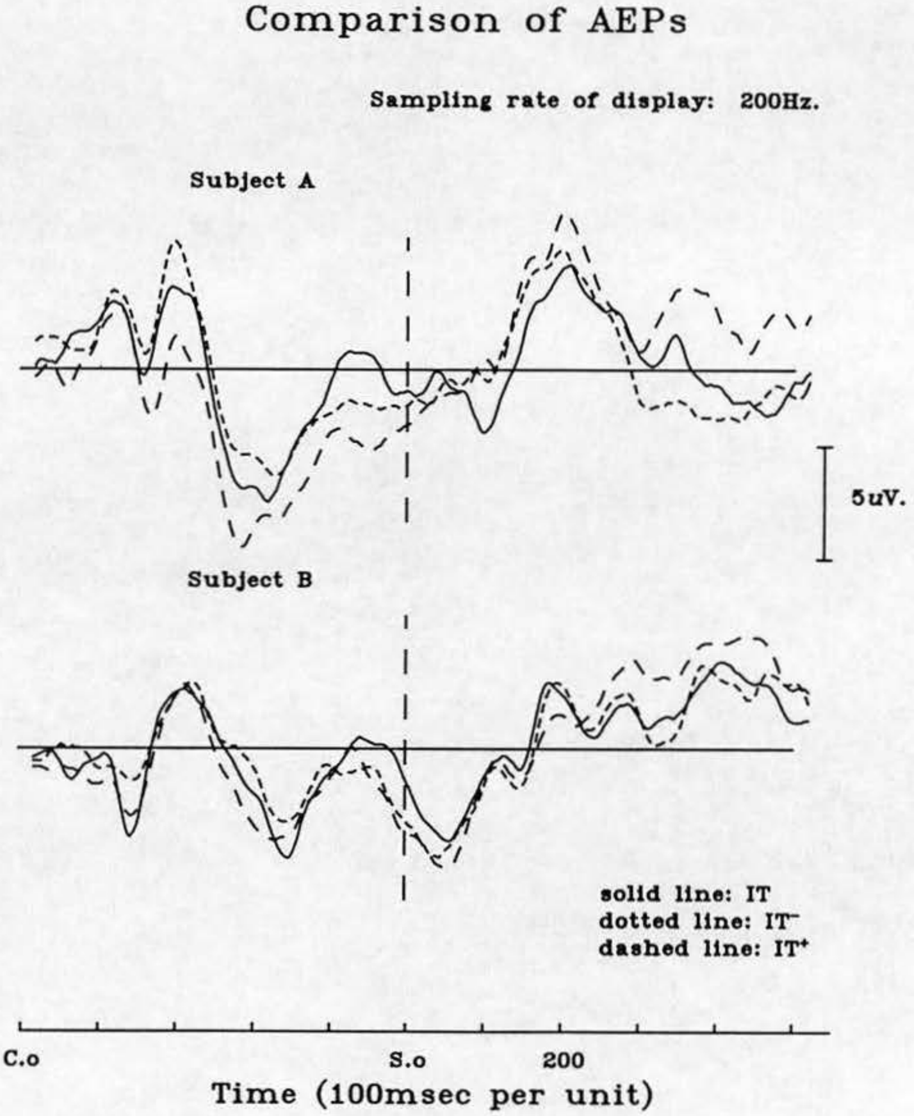


Fig. 4.2 AEPs superimposed (of the same subjects as in Fig. 4.1). Positivity upwards. Vertical line: stimulus onset.

significant differences were due to the mean amplitude in the IT^+ condition being considerably larger than those in the IT and IT^- conditions. Page's trend test (L(3,8)=104, $p<.05$ for one-tailed test) confirmed that the IT^+ type of eliciting stimuli had evoked the largest P300 amplitude, with the IT type next and the IT^- smallest. These results accord with the notion that variation in amplitude of the P300 component reflects the level of subjects' confidence in performing a task (Hillyard, 1971; Kutas *et al.* 1977; Ruchkin *et al.* 1980b; Polich, 1986).

The latency measures of the P300 component ($P300_L$) were not affected by stimulus differences (F(2,14)=0.189, N.S.). However, due to task differences this should not be considered contradictory to McCarthy & Donchin's findings mentioned in the last chapter (McCarthy, 1980; McCarthy & Donchin, 1981). In McCarthy & Donchin's paradigm, subjects can eventually find out the embedded target word even in the 'noise' condition, whereas in the IT task subjects have a limited stimulus exposure duration before the mask onset; and if that duration is too short in some trials, subjects will not be able to succeed in making a discrimination. Suppose that subjects taking part in IT experiments are aware of this nature of the IT task. They might adopt a coping strategy, i.e. giving up a trial as soon as possible when facing the situation where they find it impossible to make a discrimination on that trial because of the onset of the mask. As a result, the P300 latency will not be affected by the factor of task difficulty. Considering this interpretation together with the trend of changes of P300 amplitude under the three eliciting conditions, the obtained results were in effect consistent with the idea that the P300 component indicates the completion of the process of stimulus evaluation (McCarthy, 1980; McCarthy & Donchin, 1981).

Table 4.1
Means and S.D. of the measured parameters of
AEP components

P200 component

St.types	latency(msec)		amplitude(μV)		P200$_T$(msec)	
	Mean	S.D.	Mean	S.D	Mean	S.D.
IT$^+$	204.40	10.27	4.10	2.19	52.09	21.19
IT	200.13	10.08	3.85	1.56	50.10	17.44
IT$^-$	199.06	11.50	4.31	1.61	48.18	20.33

P300 component

	Latency(msec)		Amplitude(μV)	
	Mean	S.D.	Mean	S.D.
IT$^+$	328.70	41.09	5.26	2.47
IT	328.48	39.59	3.82	3.02
IT$^-$	331.05	41.88	3.33	3.14

(2) *P200 component* There was no variation from one stimulus condition to another in any measure of the P200 component (F(2,14)=0.711, N.S. for the amplitude measure; F(2,14)=1.959, N.S. for the latency measure; and F(2,14)=0.515, N.S. for the P200$_T$). These results are consistent with observations in other studies (Chapman & Bragdon, 1964; Courchesne, 1978), suggesting that the P200 component may reflect a process which is aroused to the same extent in all three experimental conditions. In other words, since stimulus presentation was randomized and subjects did not know which of the three types of trials (IT, IT$^+$, IT$^-$) was coming next, they were dealing with a task that was equivalent to the IT task and demanded the same mental operation at least at the beginning of each trial (Salthouse, 1985). This implies that the P200 might index a pre-discriminative process, either anticipation or encoding, which was identical no matter whether the subject was subsequently able to make a successful discrimination (Hink *et al.* 1978). The subsequent discrimination might have been carried out before the occurrence

of the P300 component (Simson *et al.* 1977; Porjesz *et al.* 1987).

(3) *IT-AEP correlations* To take this line of inquiry further, Pearson correlation coefficients were calculated between IT scores and P200 measures for the IT trials and also for all trials combined (Haier *et al.* 1983). The use of a larger number of trials (192 vs 64) in this way allowed us to improve the signal-to-noise ratio, and the combination of data from different conditions here was acceptable in the absence of any significant differences in P200 measures between conditions. Table 4.2 shows these correlations.

The correlation between inspection time and the $P200_T$ was high and positive (r=.61, n=8, n.s. for the IT trials-only calculation, and r=.85, n=8, $p<.01$, two-tailed, for the calculation across all trials). This relationship accords with the view that the P200 component (Chapman *et al.* 1978) and inspection time (Vickers *et al.* 1972) measure something in common, perhaps reflecting the processes of the encoding sensory information from iconic storage into STM.

Table 4.2
Correlations between IT and AEP measures

	$P200_T$	$P200_L$	$P200_A$	$P300_L$
Across all trials	.85**	.10	.04	.46
IT trials-only	.61	.18	-.15	.46

** p<.01, two-tailed.

There were no other significant correlations. Correlations between the IT and $P200_L$ were very low, but in the expected direction on the grounds that IQ scores have been reported to correlate negatively with both the latency measures of AEP components (Ertl & Schafer, 1969; Callaway, 1973; Hendrickson, 1973; Squires, N.K. *et al.* 1979), and the measure of inspection time (Brand & Deary, 1982; Anderson, 1986; Longstreth *et al.* 1986; Nettelbeck *et al.* 1986a).

Correlations between inspection time and P300 latency are also given in Table 4.2. There was a positive correlation between the IT measure and the latency of the P300 component, although the results did not achieve significance.

It is interesting to note that the IT-$P300_L$ correlations were higher than those of the IT-$P200_L$, suggesting that the overall process underlying IT performance has two stages (Sternberg, 1967). The first stage, which might be indexed by variation in the form of the P200 component, presumably reflects the rate of information uptake or encoding, emphasized by many authors (Vickers *et al.* 1972; Vernon, 1981; Brand & Deary, 1982; Nettelbeck, 1982; Vickers & Smith, 1986). The second stage, indexed by variation in latency of the P300 component, might reflect the process of discrimination, which presumably takes place within STM (Saccuzzo *et al.* 1979).

The horizontal bar used as the cue signal also evoked a P200 wave. To examine if variation in the P200 component measured from the stimulus onset reflected variation in the process of information encoding or whether it merely reflected variation in the process of anticipation or attention, a $P200_T$ measure was also calculated for the cue. If variation in the P200 measured from the stimulus onset merely reflected variation in the process of anticipation rather than that of information encoding, we would expect that a similar correlation between the IT score and the $P200_T$ measure measured from the cue onset should also be found. However, the correlation of the $P200_T$ measure of the P200 wave to the cue signal with subjects' IT scores was negligible (r=0.23 N.S. for all trials and r=0.27 N.S. for IT trials-only). This indicates that the relationship revealed between the P200 from stimulus onset and inspection time was not attributable simply to an attentional variable, or perhaps more precisely, a passive attentional variable.

(4) *Window analysis* The mean potential across the whole 1024 msec epoch may not be ideal as a baseline from which to measure the rate of development of the P200 component. Across the whole epoch, the averaged waveform may reflect the presence of several independent processes; for instance, attention elicited by cue signal (Hillyard *et al.* 1978; Hansen & Hillyard, 1980); expectancy manifested by CNV (Walter *et al.* 1964); and evaluation reflected by components from the P300 onwards (Pritchard, 1981). The mean value of the potential across this epoch would depend on the net contribution of these independent processes, and might (for example) be lowered in subjects showing pronounced CNV in anticipation of the task stimulus, and raised in subjects showing a large or prolonged P300 wave. In order to separate the effects of these processes which are remote from stimulus encoding and to refine the $P200_T$ measure in order to provide an index of this initial intake process only, a window from 75 msec to 275 msec from the stimulus onset, centred by the N150-P200 complex, was defined for this purpose (Bentin *et al.* 1985). The mean potential across the window was used as a baseline from which to measure both $P200_T$ and $P200_A$ (see Section 3.3). The results of this window analysis are given in Table 4.3. In the data from the IT trials-only condition, the correlation between inspection time and $P200_T$ measures increased to 0.77 ($p<.05$, two-tailed), whereas little change was seen for the IT correlation with the $P200_T$ measure across all trials ($r=.84$, $p<.01$, two-tailed).

Table 4.3
Correlations between IT score and P200 measures under window analysis

	(Window: 75-275 msec) $P200_T$	 $P200_A$
Across all trials	$.84^{**}$	-.32
IT trials-only	$.77^{*}$	-.37

* p<.05; ** p<.01, two-tailed.

(5) *Test-retest and inter-observer reliability of the AEP measures* Each AEP trace was scored on two occasions (separated by a week) for the $P200_L$, $P200_A$, and $P200_T$ parameters, by each of two judges (YZ, PC). The inter- and intra-observer reliabilities were examined, and Pearson correlation coefficients between judges and between sessions were all high, ranging from .95 to .99 (Table 4.4). The raw data is listed in Appendix A.

Table 4.4
Correlations between judges (A,B) and between sessions (1,2)

(n=8)	Parameters								
	$P200_L$			$P200_A$			$P200_T$		
	A1	A2	B1	A1	A2	B1	A1	A2	B1
A2	.961			.997			.961		
B1	.966	.953		.972	.979		.980	.973	
B2	.963	.992	.970	.998	.999	.976	.958	.998	.969

4.1.3. Summary

One of the interesting findings in this experiment was the correlation between inspection time and $P200_T$ measure (r=0.85, n=8, p<.01, two-tailed). The high correlation of the $P200_T$ with inspection time was increased by improving the signal-to-noise ratio (i.e. by averaging across all trials as opposed to across IT trials only) and also by the use of window analysis. This IT-P200 association offered some corroboration for both Vickers' and Chapman's propositions and indicated that both the IT and P200 measures reflect something in common.

The correlations of other P200 parameters with inspection time were close to zero. The correlations between the IT estimate and P300 latency were indicative and interesting, but non-significant.

The implications of the above findings are as follows. On the one hand, the inspection time may vary as a function of variation in the speed of encoding sensory information from iconic storage into STM, faster encoding presumably being reflected by smaller values of the $P200_T$ measure. On the other hand, a second process (whose speed or efficiency affects the IT measure) might take place within the range from the peak of the P200 component to the peak of the P300 component, and reflect the actual analysis of the encoded information. The next experiment intends to control some types of these eliciting stimuli and to replicate the above results at the same time.

4.2. Experiment 2

In Exp. 1, it was found that there was significant positive correlation between inspection time and $P200_T$ measures, and the variation in the exposure durations of the discriminative stimuli did not affect the form of the P200 component at all. On the other hand, it was found that variation in the exposure durations of the stimuli had significant effects on the amplitude of

P300 component ($P300_A$), but not on its latency ($P300_L$). To explain these findings, it was assumed that the $P200_T$ measure is sensitive to the process of sensory information encoding (Chapman *et al.* 1978), and that the P300 component may indicate the completion of the evaluation of encoded information (McCarthy & Donchin, 1981).

However, because the exposure durations of the discriminative stimulus in Exp. 1 depended entirely on the estimated IT scores of individual subjects (i.e. IT duration, IT^+ (ITx1.75) duration and IT^- (ITx0.25) duration), we need to examine whether the P200 measures under different conditions of exposure duration of the discriminative stimulus vary only as function of task requirement (i.e. the process of encoding), or whether they depend on the particular exposure duration used to elicit ERPs (Donchin *et al.* 1963). The present experiment, then, tried to control experimentally some aspects of the eliciting stimuli so that the effect of task requirement on variation in form of the P200 could be monitored. At the same time, an attempt was made to replicate the IT-$P200_T$ relation observed in Exp. 1.

4.2.1. Methods

1) Subjects. Five male and three female students ranging in age from 20 to 29 years (mean=23.0, S.D.=2.64) participated in the present experiment. They had normal, or correct-to-normal, vision.

2) Stimuli. Cue signal and test Stimuli used in this experiment were the same as described in the pilot study (see Section 2.2.2) (Diagram 2.1). Four subjects were asked to press the lever on the side at which the longer vertical line had appeared in the discriminative stimulus. The others responded to the shorter line. The presentation of the two types of stimuli (longer line on the left or on the right) was randomized, and so was the post-response interval,

which varied within the range of 2-3 seconds. Subjects were told not to make their response until the mask disappeared.

3) Types of stimuli to elicit ERPs. Apart from the IT-type eliciting stimuli, two other types of stimuli were used in this experiment to elicit ERPs. They were the non-masked exposure of the discriminative stimulus, and the mask-only exposure. In the IT-type condition (see Exp. 1) the discriminative stimulus was presented for a duration equal to the subject's IT estimate, followed by the backward mask, and the overall duration from stimulus onset to mask offset was 600 msec. In the non-mask condition, the discriminative stimulus was illuminated for 600 msec (non-mask type), and in the mask-only condition the mask was presented to the subject for an equivalent period (mask-only type) (Diagram 4.2).

Compared with the IT^{+} and IT^{-} conditions of the previous experiment, the non-masked and mask-only conditions were intended not only to make the discrimination very easy (exposure of the discriminative stimulus without mask) or very hard (i.e. impossible: exposure of the mask with no preceding discriminative stimulus), but also to serve as control conditions because both conditions were exactly same for every subject. As all stimuli were intermixed and presented in a random sequence, subjects had to encode a certain amount of information from iconic storage into STM before they could make a decision even under the mask-only condition in which the 'stimulus' was not informative.

4) ERP data recording. The recording arrangement was the same as was used in the previous experiments (see Section 2.2.3). The three types of stimuli employed were described above. As before, all stimuli were intermixed and presented in a random sequence. 210 samples were collected from each

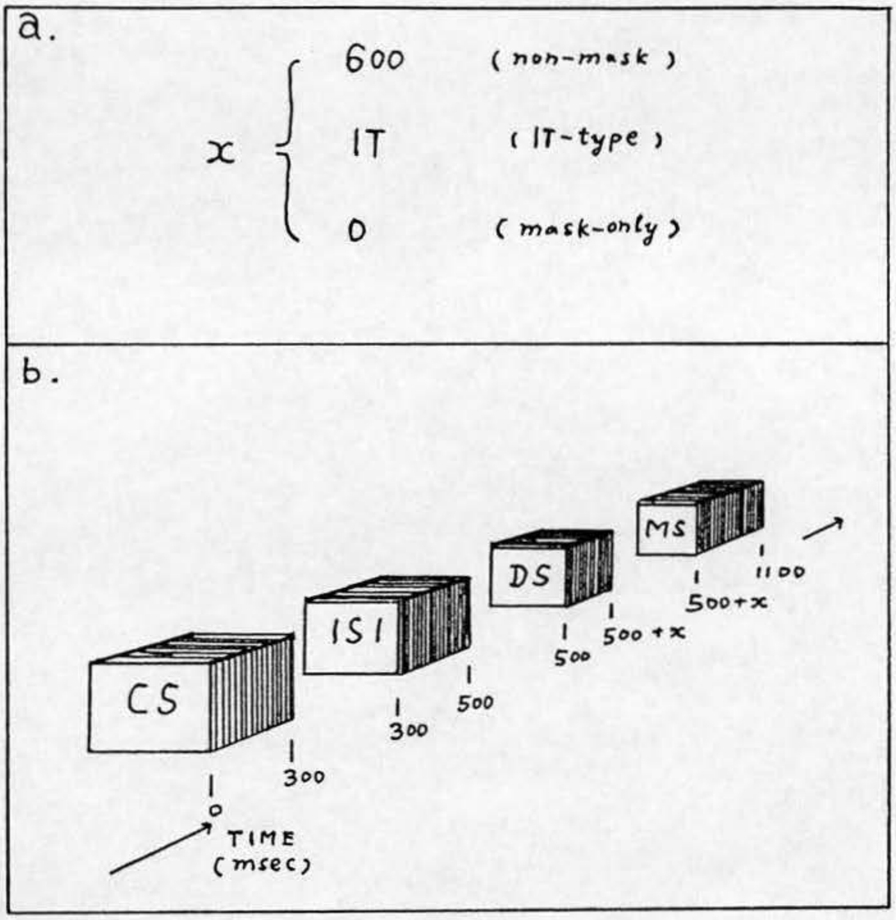


Diagram 4.2

Diagram 4.2a shows the exposure durations of the discriminative stimulus. Diagram 4.2b outlines the procedure. CS: cue signal; ISI: inter-stimulus interval; DS: discriminative stimulus; MS: backward mask.

subject with each type of stimulus being presented 70 times. The sampling started from the cue onset. As in Exp. 1, the cue occurred 500 msec before the onset of the discriminative stimulus and lasted for 300 msec (Diagram 4.2).

5) Procedure. As in the previous study, subjects went through sessions of practice, inspection time estimation, electrode placement, and ERP recording in that order. Subjects' inspection time was defined as the minimum stimulus exposure duration required to achieve 90% correct responses. The skin resistances were monitored before and after the experiment. The average was 4.57 Kohm with the S.D. being 2.09 Kohm.

6) Data analysis and measures. No subjective editing was used. Three average waveforms, corresponding to the IT-type, non-masked, and mask-only exposure conditions respectively, were obtained for each subject. Each AEP was calculated from the first 64 samples of each category. After averaging, these AEPs were smoothed using the filter (see Section 2.3.1).

As in Exp. 1, several parameters of AEP components were measured in this experiment, including the $P200_L$, the $P200_A$, the $P200_T$, the $P300_L$ and the $P300_A$. the definitions of these measures were the same as before (see Sections 3.3 and 4.1.1).

4.2.2. Results and discussion

Subjects' IT scores ranged from 17 msec to 38 msec (mean=28.12, S.D.=9.57). The relatively long IT estimate of some subjects in Exp. 1 was not seen in these subjects.

Fig. 4.3a shows the superimposed traces of one subject, and Fig. 4.3b the superimposed grand means of the eight subjects. Table 4.5 lists means and standard deviations of the parameters of AEP components.

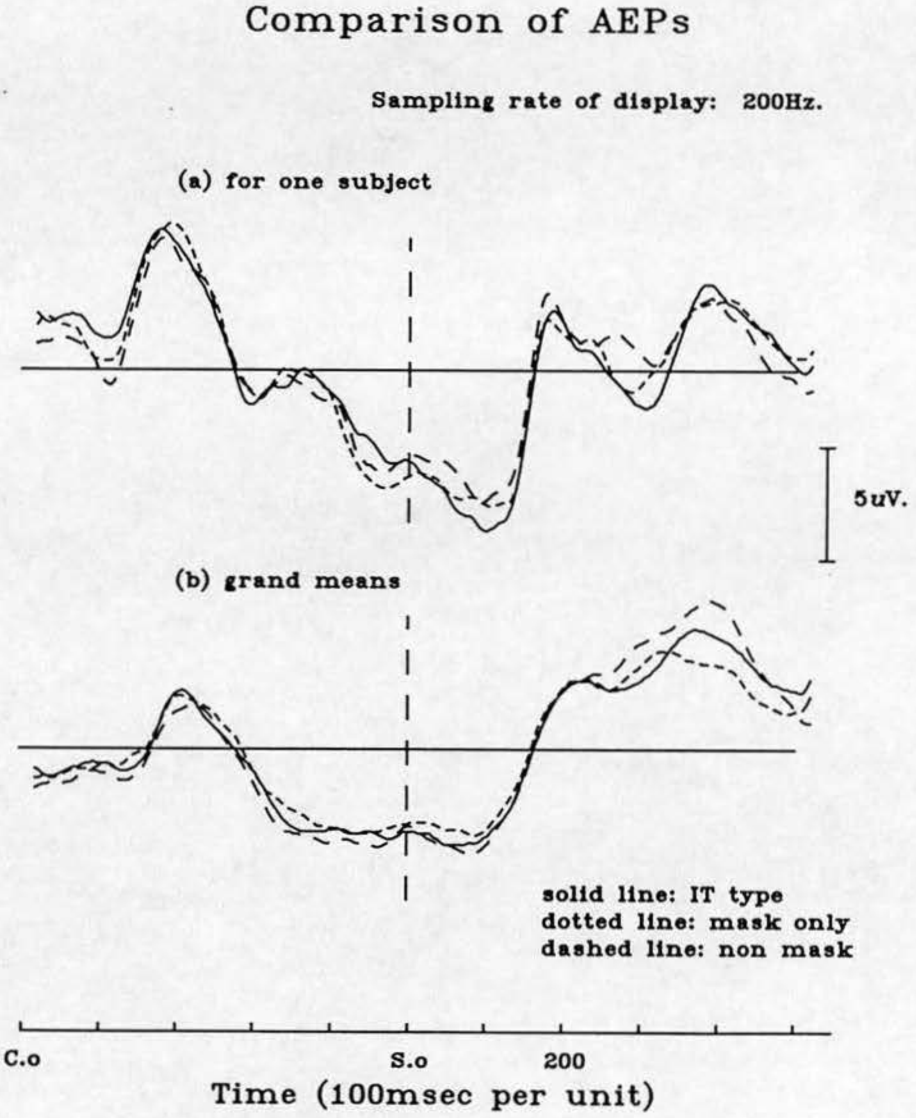


Fig. 4.3 Superimposed AEPs. Positivity upwards.
Vertical line: stimulus onset.

Table 4.5
Means and standard deviations
of the AEP parameters concerned

Stimuli	$P200_L$(msec)		$P200_A$(μV)		$P200_T$(msec)	
	Mean	S.D	Mean	S.D	Mean	S.D.
non-mask	206.13	20.80	3.73	1.92	44.25	20.58
IT-type	206.75	19.01	3.46	1.78	44.56	16.11
mask-only	201.19	20.80	3.39	1.50	41.56	18.09
	$P300_L$		$P300_A$			
non-mask	335.13	50.08	6.87	4.45		
IT-type	331.63	55.99	5.75	3.79		
mask-only	320.81	49.85	5.21	3.14		

(1) *P300 component* Results of analysis of the P300 component obtained in this experiment were similar to those found in Exp. 1. There was no significant difference in the P300 latency between the three different stimulus conditions ($F(2,14)=1.821$, N.S.). However, it looked as if there was a systematic decrease in the latency of the P300 component from the non-mask condition (335.13 msec) to the mask-only condition (320.81 msec) (also see Fig. 4.3b), which was in support of the 'strategy theory' proposed in Exp. 1, i.e. subjects tend to give up a trial quickly if they perceive that it is impossible to make discrimination on that trial. A comparison between the non-mask and mask-only measures of the P300 latency revealed a significant difference ($t=2.392$, $df=7$, $p<.025$ for one-tailed test).

The amplitude of the P300 component *was* affected significantly by different types of eliciting stimuli ($F(2,14)=4.336$, $p<.05$). Page's trend test ($L(3,8)=105$, $p<.05$) disclosed again that the easiest IT task (non-mask condition) had evoked the largest amplitude (mean=6.87 μV), with the IT-type condition next (mean=5.75 μV) and the mask-only condition having the smallest amplitude (mean=5.21 μV). These findings confirmed the idea that the P300 amplitude reflects the subject's confidence in his/her performance of the task (Hillyard, 1971; Kutas *et al.* 1977; Ruchkin *et al.* 1980b), as well as supporting the hypothesis that the occurrence of the P300 component indicates the completion of the process of stimulus evaluation (McCarthy & Donchin, 1981).

(2) *P200 component* Three measures of each parameter of the P200 component were again quite similar (Table 4.5 and Fig. 4.3). An one-way ANOVA for repeated measures did not show any differences between the three eliciting conditions for either the $P200_L$ (F(2,14)=2.118, N.S.), or the $P200_A$ (F(2,14)=0.637, N.S.). These results suggested that an identical, individually characteristic P200 component was produced under all three conditions (Andreassi *et al.* 1976), reflecting their common requirement for information encoding as a prelude to stimulus analysis (Chapman *et al.* 1978; Hink *et al.* 1978).

(3) *IT-AEP correlation* Since no difference was found for the P200 parameters and the P300 latency, this experiment also provided an opportunity to look at the relations between inspection time and these AEP parameters across all trials as well as for IT trials only.

Pearson product-moment correlation coefficients were calculated between inspection time and AEP measures for whole epoch analysis, where the mean potential was based on the epoch of 1024 msec from cue onset. The results are shown in Table 4.6. As can be seen, the IT-$P200_T$ correlations were again the highest of any measures; but, although high in this experiment, they did not reach significance (r=.50, n=8, N.S. for all trials, and r=.53, n=8, N.S. for IT trials-only). The IT-$P300_L$ correlations were higher than those of the IT-$P200_L$.

Table 4.6
Correlations between
inspection time and AEP parameters concerned

(n=8) Calculation conditions	$P200_T$	$P200_L$	$P200_A$	$P300_L$
Across all trials	.50	.20	.33	.35
IT trials only	.53	.13	.38	.26

Using the window analysis (i.e. the portion 75-275 msec from stimulus onset) correlations between IT scores and the $P200_T$ measure decreased in magnitude this time (r=.37 for all trials and r=.34 for IT trials-only). However, for the purpose of replication it was difficult to come to a firm conclusion about the IT-$P200_T$ relationship on the basis of the correlations in this experiment alone. Taking into account the small sample of subjects (n=8) and the restricted spread of IT estimates in this experiment (17-38 msec) compared with Exp. 1 (18-78 msec) (Fig. 4.4), the absence of a significant correlation might have been a Type II error (Fig. 4.5). In order to minimize these problems in the present situation, the results of Exp. 1 and 2 were analysed together. The outcome of this analysis is given in next section.

4.3. Combined results of Exp. 1 & 2

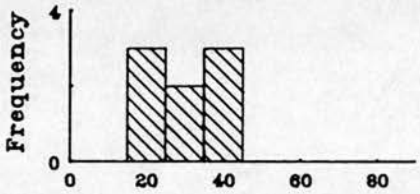
For the 16 subjects in Exp. 1 and 2, the mean IT was 31.12 msec with the S.D. being 15.85 msec. The other results were as follows.

4.3.1. IT-AEP correlations

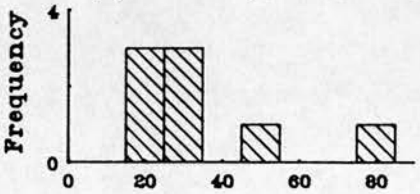
Table 4.7 contains the correlations between IT and AEP measures for the 16 subjects in Exp. 1 and 2. Considering the different conditions imposed on

Distribution of ITs

(a) for the present study



(b) for the previous study



(c) a combined distribution

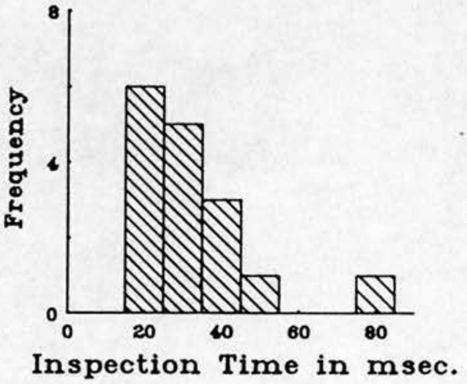


Fig. 4.4 Histogram of subjects' Inspection Times.

Scatterplot of $P200_T(w)$ against IT

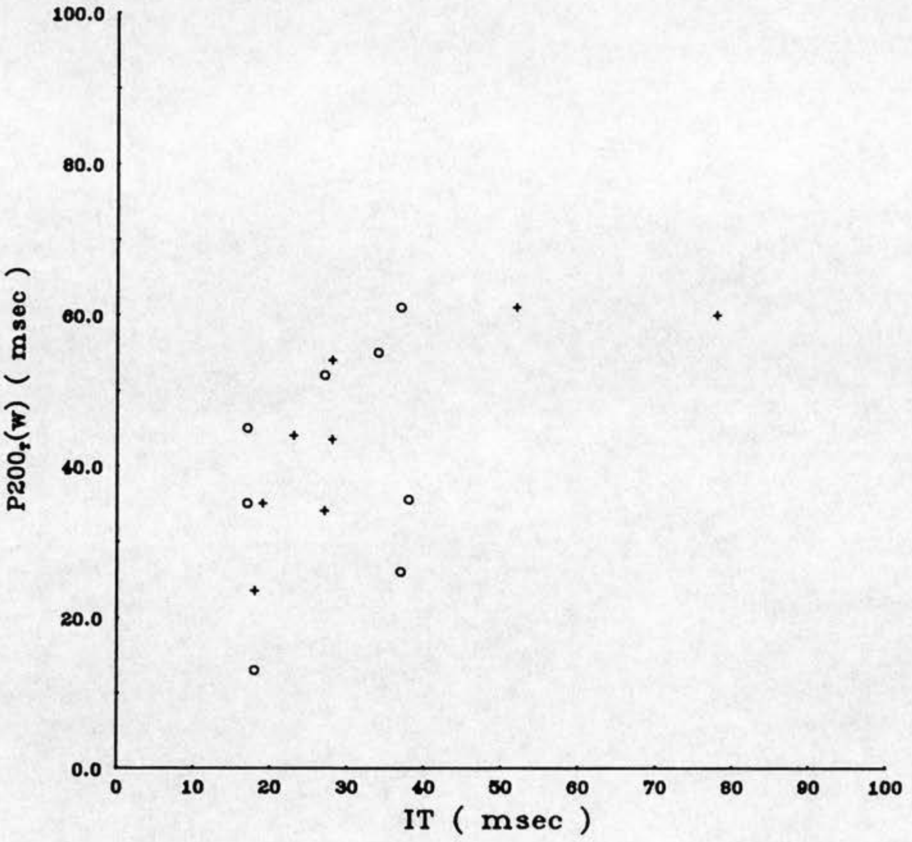


Fig. 4.5 $P200_T(w)$ of AEPs plotted against IT for sixteen subjects. $P200_T(w)$: $P200_T$ measure of the 75–275msec window analysis. Cross: Experiment 1; Open circle: Experiment 2.

subjects in the two experiments, the calculation was carried out only for the IT-type stimulus condition which was the same in both experiments.

Table 4.7
Correlations between inspection time and
AEP measures among 16 subjects in Exp. 1 & 2

Analyses	IT trials only		
	$P200_T$	$P200_A$	$P300_L$
Whole epoch	.452	.071	.306
Window	.570*	-.223	

* p<.05, two-tailed.

As can be seen from Table 4.7, inspection time correlated with the $P200_T$ measure of the window analysis (r=.570, n=16, p<.05, two-tailed), but not with the $P200_T$ of the whole epoch (r=.452, n=16, N.S.). This finding warranted further investigation.

4.3.2. Effects of response requirement

Out of 16 subjects in the two experiments, 8 were required to indicate at which side the longer vertical line had appeared in the stimulus display, and the rest were required to respond to the shorter line. The IT estimate, however, was not affected by subjects' responding to different stimulus lines (Mann-Whitney U(8,8)=28.5, N.S.). Also, no difference was found between the two groups either for the $P200_T$ measure (Mann-Whitney U(8,8)=30.0, N.S.), or for the $P300_L$ measure (Mann-Whitney U(8,8)=16.0, N.S.). These results suggested that it is not necessary to control this variable in future experiments.

4.3.3. Sex differences

There were 9 male and 7 female subjects in Exp. 1 and 2. Mann-Whitney tests showed no differences between the two groups either for the IT measure (U(7,9)=24.5, N.S.), or for the $P200_T$ measure (U(7,9)=31.0, N.S.). Therefore, having a roughly equal number of subjects of both sexes is not necessary in future experiments.

4.4. Summary

In general, Exp. 2 obtained similar results to those in Exp. 1. The main findings from the two experiments were as follows.

1) The P200 component had little to do with variation in the exposure duration of the discriminative stimulus, as far as individual subjects were concerned; and it was mainly related to the general requirements of the inspection time task.

2) The amplitude of the P300 component varied as a function of the types of discriminative stimuli, which determined the levels of task difficulty. A larger $P300_A$ was seen if an IT trial was relatively easy.

3) On the assumption that the small sample size might have been responsible for the non-significant IT-$P200_T$ correlation observed in Exp. 2, the results of Exp. 1 and 2 were combined, and this produced a significant correlation ($r=.570$ $n=16$, $p<.05$, two-tailed) between IT scores and $P200_T$ measures evoked by IT-type trials and subject to the window analysis among the 16 student subjects.

Given the characteristics of the inspection time task, these findings thus suggest that the P200 component may be the cortical correlate of the encoding of sensory information from iconic storage into STM (Chapman *et al.* 1978), and that the P300 component may reflect the completion of evaluation of the encoded information (McCarthy & Donchin, 1981). Also, the IT-P200 association provides empirical evidence for the validity of inspection time as a measure of an input process (Vickers *et al.* 1972; Kirby & McConaghy, 1986).

Additionally, the combined results indicate that it is neither necessary to have equal numbers of both male and female subjects, nor to balance among subjects the response requirements, i.e. longer vertical line or shorter vertical line to which subjects are asked to respond.

CHAPTER 5

EXPERIMENT 3: ENCODING AND EVALUATION

5.1. Introduction

Apart from the relation between the inspection time estimate and the P200 component observed in Exp. 1 & 2, it was found that task difficulty did not affect the P300 latency, although it had significant effects on the P300 amplitude. In the light of the previous analysis of the P300 component (Donchin, 1981; McCarthy & Donchin, 1981; Pritchard, 1981) this observation has been interpreted in terms of the 'strategy theory'; i.e. subjects who are aware of the nature of the IT task may give up a trial as soon as possible if they perceive that it is impossible to make a discrimination on that trial. In Exp. 2, where the levels of task difficulty were further separated from one another, the results seemed to agree with the above interpretation in the sense that the P300 latency was longer for the easiest task condition (non-mask) than for the most difficult condition (mask-only) ($p<.025$ for one-tailed test) (see Section 4.2.2).

However, increasing the difference between levels of task difficulty might not provide clear evidence in favour of this interpretation. Even though a trial is intended to be easy, subjects may on some occasions (because of inattention, etc.) find it impossible to make the discrimination. Similarly, it can not be taken for granted that every trial intended to be difficult will be equally hard for the subject. Suppose that subjects are less likely to emit an incorrect response if they have made every effort to discriminate on a trial than if they have relaxed their efforts to make the discrimination at an early stage. The behavioural response following each trial may serve as a criterion against which the 'strategy theory' previously described might be tested. This can be done by dividing the recorded ERPs of each subject into two groups, one containing the recordings which are followed by a correct judgment and the other the recordings followed by a wrong judgment. Given that the P300 latency indicates the completion of stimulus evaluation processing (McCarthy & Donchin, 1981), the hypothesis would be that, if the 'strategy theory' is correct, the P300 latency would be shorter for the AEP derived from ERPs of the wrong group than for the AEP derived from ERPs of the correct group.

Regarding experimental procedure and design, two conclusions of importance emerged from the earlier work. It was found that the duration of exposure of the discriminative stimulus did not have marked effects on most parameters of AEP components concerned. Therefore, it may be possible to analyse the IT-P200 relation without the use of standardized levels of exposure duration of the discriminative stimulus. In other words, subjects' ERPs may be collected directly from a session in which their IT scores are being assessed. Also, it was found that variables such as sex and the instructions to respond to the longer or the shorter vertical line of the discriminative stimulus did not affect the measures with which we are concerned, indicating that it is not necessary to control for these variables in the future. Thus we can simplify the procedure and design of subsequent experiments.

In this experiment, subjects' ERPs were recorded while they were carrying out a 'real' inspection time task. One object of this experiment was to observe whether the IT-P200 relation could be replicated after changes in the experimental procedure had been made. The other object was to test the hypothesis described above, i.e. that the P300 component might show a longer latency when the subject is going to respond correctly and a shorter latency when the subject is going to make a mistake.

5.2. Methods

1) Subjects. 16 subjects (13 male and 3 female) of the general population took part in the experiment. They had normal or corrected-to-normal vision. The ages in this group ranged from 15 years to 47 years (Mean=28.12, S.D.=7.99).

2) Stimulus. Test stimuli used in this experiment were the same as described in the previous studies (see Section 2.2.2), except that the backward mask was no longer in the shape of the rectangle (see Section 2.2.2), but in the shape of an inverted-U (Diagram 5.1). (The bottom line of the previous rectangular mask was omitted.)

Unlike the previous experiments which employed the horizontal bar 18mm long in the low part of the display panel on the front of the LED box as the cue signal, the cue signal used in this experiment was the rectangular display (26mm long and 18mm wide), which was previously used as the mask (Diagram 5.1). The timing relations between the cue and test stimulus remained intact; i.e. the cue occurred 500 msec before the test stimulus onset and lasted for 300 msec, and test stimuli had a duration of 600 msec.

For the IT task, all subjects in this experiment were required to respond to the longer vertical line of the discriminative stimulus. They were instructed not to initiate their response until the test stimulus had disappeared. The order of presentation of the two discriminative stimuli (Long-Left or Long-Right) was

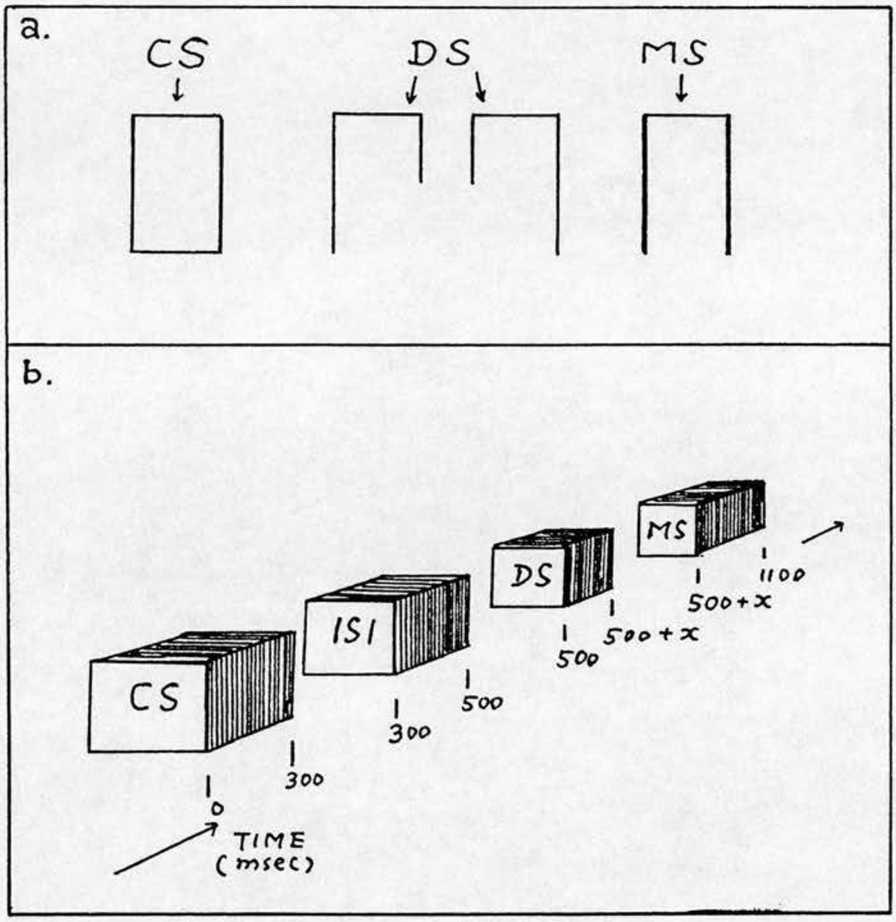


Diagram 5.1

Diagram 5.1a shows the patterns of stimuli used. Diagram 5.1b outlines the procedure. CS: cue signal; ISI: inter-stimulus interval; DS: discriminative stimulus; MS: backward mask.

randomized, and the post-response interval varied randomly over the range of 2-3 seconds.

3) ERP data recording. The recording arrangement and electrode placement remained as before. Sampling epoch was also 1024 msec, starting from cue onset. 100 ERP samples were taken from each subject while their IT was being tested. The exposure duration of the discriminative stimulus was fixed at the subject's estimated IT score as soon as it was found out, so that the ERP sampling could continue till the 100 recordings were collected.

4) Procedure. As before, subjects had a practice session, which was followed by the electrode placement. The skin resistances were monitored before and after ERP sampling. The mean resistance was 5.34 Kohm with the S.D. being 1.55 Kohm. Subjects then moved on to the IT estimation, and their ERPs were recorded at the same time. In contrast to the criterion of 90% correct responses used in the previous experiments, in this experiment the inspection time was defined as the minimum stimulus exposure duration required to make 85% correct responses (Wilson, 1984), the intention being to cut down the number of trials needed to complete the IT estimation (Taylor & Creelman, 1967).

5.3. Results and discussion

5.3.1. Effect of adopting the 85% accuracy criterion

The mean IT score in this experiment was 23.87 msec with the S.D. being 6.98 msec. Comparing the mean with those obtained in Exp. 1 and 2 (32.12 msec and 28.12 msec respectively), the reduction in the mean IT score indicated the effect of the lower accuracy criterion (85%) used in the present experiment, although the difference between them was not significant (Mann-Whitney U(16,16)=97, N.S.).

On the other hand, the 85% accuracy criterion had an obvious advantage. It cut down on the time needed for testing subjects' inspection time by almost half when compared with the previous (90% accuracy) criterion.

5.3.2. Influence of the cue

The cue signal in the present experiment had a conspicuous shape and was considerably brighter than that in the previous experiments. Its effect on the evoked potentials to test stimuli is illustrated in Fig. 5.1. In contrast to the P200 component of the AEP to the cue, the P200 component of the AEP to the test stimulus was smaller than those seen previously (Fig. 4.2 and 4.3). This effect led to a decision that the whole-epoch $P200_T$ measure should be rejected. Because the wave elicited by the cue made a significant contribution, it would not make sense to use the mean potential of the whole epoch to define a reference so that the $P200_T$ measure could be taken.

5.3.3. IT-AEP relation

This experiment collected 100 ERP samples from each subject. This number exceeded by a large amount the minimum of 64 samples for averaging. Therefore, it was possible to exclude some very aberrant recordings from averaging. For this purpose, cluster analysis (BMDP2M, Dixon, 1983) was employed. Before this analysis was implemented, the epoch of each individual recording starting from test stimulus onset onwards was smoothed by the filter. The cluster analysis was performed on the 100 smoothed traces of each subject, with each trace being treated as a case. The centroid rule of amalgamation was used for the analysis. Those traces which had an amalgamation distance shorter than 7.99, as revealed by the analysis, were

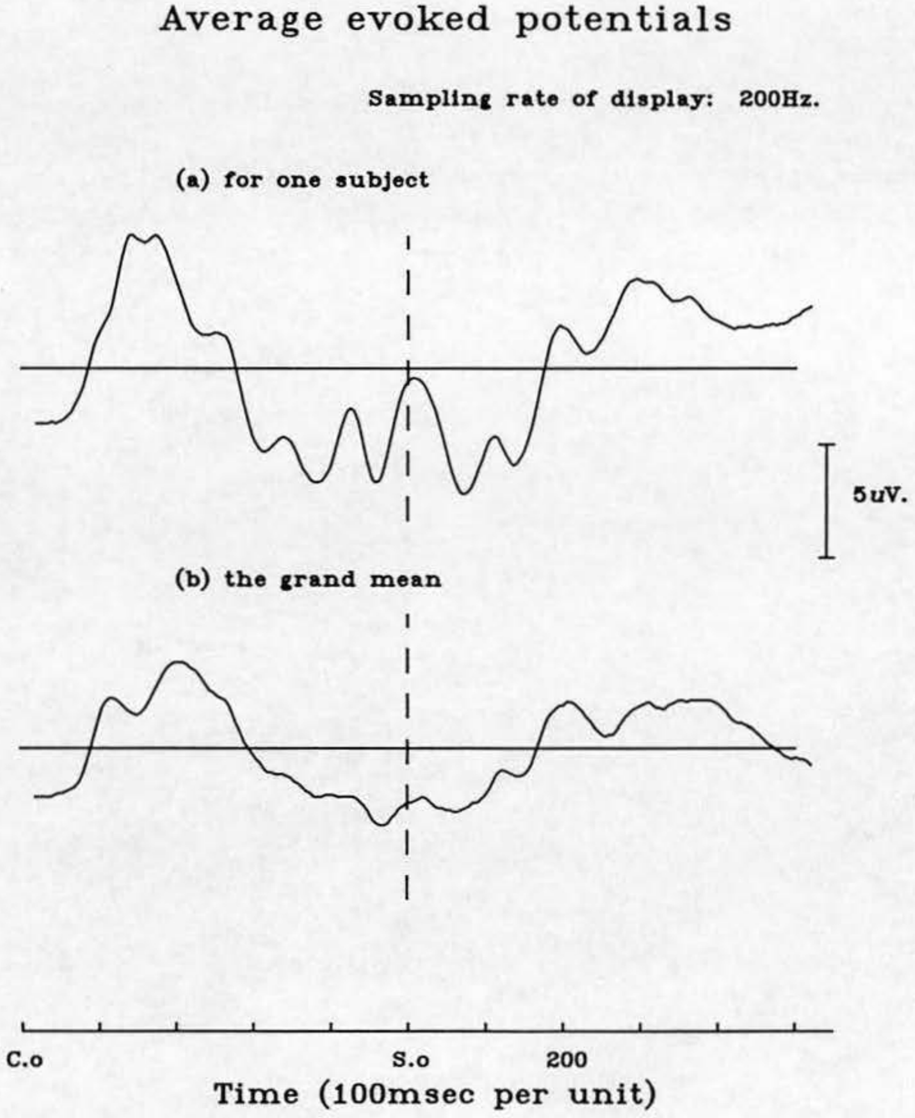


Fig. 5.1 AEP of one subject and the grand mean of 16 subjects. Positivity upwards. Vertical line: stimulus onset. Horizontal line: mean potential.

then averaged for each subject.[1] The number of traces being averaged was different from one subject to another, and varied within the range of 77 to 94.

Measures taken in the present experiment included the P200 latency ($P200_L$), the P300 latency ($P300_L$), the $P200_T$ of the 75-275 msec window analysis ($P200_T(W)$), and the $P200_A$ of the 75-275 msec window analysis ($P200_A(W)$). With the intention of exploring the relation between the N150-P200 complex and IT measure, the peak-to-peak amplitude of the N150-P200 complex was also taken in the present experiment. Definitions of the P200 and P300 components were the same as described previously, and the N150 component was defined as the negative deflection preceding the P200 component. Table 5.1 lists means and standard deviations of the AEP parameters concerned.

Table 5.1
Means and standard deviations
of the AEP parameters concerned

	$P200_L$(msec)	$P200_A(W)$(μV)	$P200_T(W)$(msec)
Mean	182.25	2.14	33.16
S.D.	17.64	0.96	8.10

	$P300_L$	Amplitude of N150-P200
Mean	331.28	5.07
S.D.	43.46	1.69

The correlations between these AEP parameters, the IT measure and age are given in Table 5.2. First, the positive correlation between IT score and

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[1] That the amalgamation distance of 7.99 was used was a compromise decision with the principal concern of retaining at least 64 ERP samples for each average.

$P200_T(W)$ measure was observed again (r=.44, n=16, p<.05, one-tailed). Second, the peak-to-peak amplitude of the N150-P200 complex correlated negatively with subjects' age (r=.49, n=16, p<.05, one-tailed), which was consistent with observations of other authors (Squires, K.C. *et al.* 1979). Third, there was a positive IT-$P200_L$ correlation (Ertl & Schafer, 1969; Callaway, 1973; Hendrickson, 1973).

Table 5.2
Correlation coefficients between relevant measures

(n=16)	Inspection time	Age
P200 latency	.41	.32
$P200_T(W)$	.44*	-.11
$P200_A(W)$	-.11	-.29
P300 latency	.28	-.32
Amplitude of N150-P200	.07	-.49*
Age	-.27	

* p<.05, one-tailed.

Taking into account the fact that the age of subjects was widely spread in this experiment, it seemed worthwhile to look at the partial correlations between IT and AEP measures after the effect of age was taken out (Beck & Dustman, 1975). By so doing, it was found that the IT-$P200_L$ correlation increased up to .55 (p<.05, df=13, two-tailed), and the IT-$P200_T(W)$ correlation remained almost unchanged (r=.43, df=13, p<.06, one-tailed). There were no other noteworthy changes.

These results not only confirmed that the IT-$P200_T(W)$ correlation is reliable, but also suggested that this relationship may exist for the temporal measures of P200 component (i.e. $P200_T$ and $P200_L$) in general, rather than being confined to one particular temporal measure of the P200 component.

The implication of this IT-P200 relation is that the fast and early occurrence of the P200 component may indicate a high speed of sensory information intake. Also, it seemed that changes in the accuracy criterion (85%) of IT estimation had done no harm in terms of preventing us from observing the IT-P200 relation.

5.3.4. $P300_L$ and discriminant analysis

According to the 'strategy theory' described in Exp. 1 (see Section 4.1.2), we would predict that the the P300 latency would have been longer when a subject was going to make a correct response than that when he was going to make an incorrect one. To examine this prediction, the smoothed individual traces were divided into two groups depending on whether the subsequent response was correct or incorrect.

Considering the fact that in the IT paradigm subjects have to guess at which side the longer line had appeared if they are not sure, a record of a correct response does not ensure that subjects have in fact discriminated the stimulus correctly: they may have made a successful response by chance. Therefore, instead of averaging directly those smoothed traces which had the same behavioural identification (i.e. correct or incorrect), stepwise discriminant analysis (Squires & Donchin, 1976; BMDP7M, Dixon, 1983) was used to divide the 100 traces of each subject into two groups according to the behavioural criterion (correct vs incorrect), one group being the 'correct' group and the other the 'wrong' group. Here, the idea was to separate the 'guesses' from the successful discriminations within the correct group; guesses which were correct should produce ERPs which resembled the wrong responses, which were guesses themselves. In the stepwise discriminant analysis, the 100 traces of each subject were treated as cases. Each case had 51 time points (or variables), which represented 500 msec epoch of the AEP from the onset of the stimulus.[2]

The mean percentage of correct classification by the stepwise discriminant analysis was 75% for correct responses, 74% for wrong responses, and 75% for the total. Due to having very few cases in the 'wrong' group, one subject's data was prevented from being averaged after discriminating. The ERP cases of the rest were summated for the two groups respectively. Fig. 5.2 presents the two averages, one for the 'correct' group and the other the 'wrong' group. The P300 amplitude was smaller for 'wrong' group than for 'correct' group, which was consistent with the observations in the previous experiments. The P300 latency was shorter for the 'wrong' than for the 'correct', providing evidence to support the 'strategy theory', i.e. that subjects tend to give up the task if they perceive that it is impossible to make a discrimination and, consequently, they release a wrong response. Also, it was compatible with the idea that the P300 indicates the completion of stimulus evaluation (McCarthy & Donchin, 1981). Since some subjects had only few cases in the 'wrong' group, no further tests were carried out.

There was also a difference in latency between the P200 components. The P200 latency was shorter for the 'correct' group than for the 'wrong' group. This point will be addressed in next chapter (see Section 6.3.3).

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[2] The grouping variable in this stepwise discriminant analysis was behavioural response with code 1 for correct and code 2 for incorrect. 30 time points corresponding to the 150-450 msec portion of that epoch were used for discriminating. This was because only this portion appeared to be relevant to the present concerns. The 30 time points were entered into the classification function without regard to the F-to-enter limit, and could not be removed from the function once entered. The tolerance level of the analysis was set at 0.01.

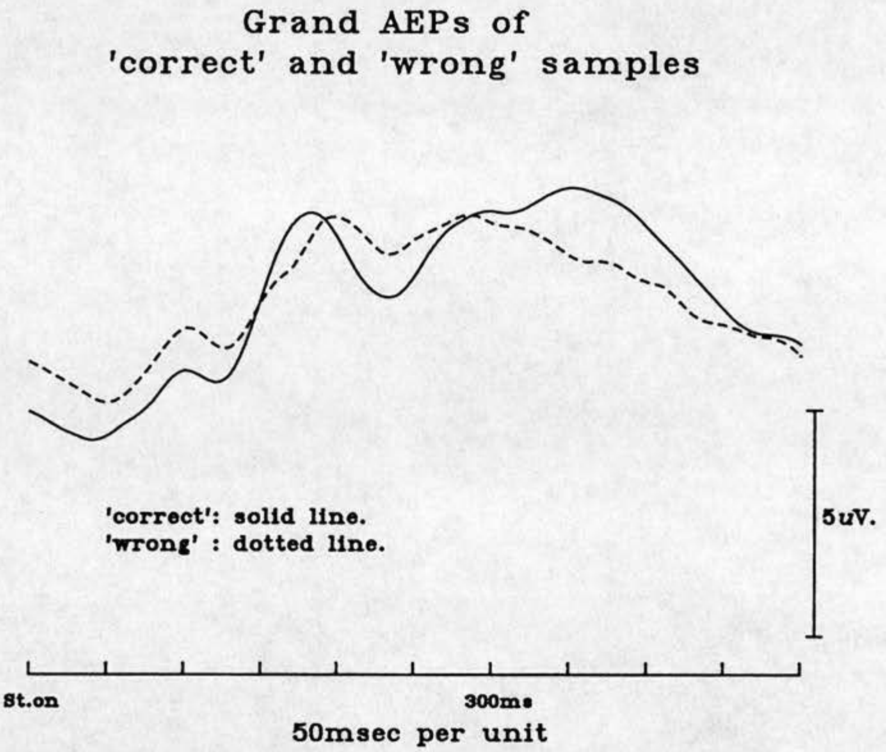

Fig. 5.2 Average of the 'correct' group and average of the 'wrong' group. The two groups were classified by discriminant analysis. Data was from 15 subjects. Positivity upwards.

5.4. Summary

In this experiment, it was found that the P200 latency could be related to the IT measure ($r=.55$, $df=13$, $p<.05$, two-tailed, controlled for age), as well as the $P200_T$ of the 75-275 msec window analysis ($r=.44$, $n=16$, $p<.05$, one-tailed). These results indicate that the relation between inspection time and the P200 component may exist for the temporal measures of the P200 component in general. It seems that subjects' age needs to be controlled in such analyses. The 85% accuracy criterion in IT estimation is viable in terms of observing the IT-P200 relation.

The previous interpretation of the role that the P300 latency may play in the IT task was supported in this experiment. A short P300 latency and low P300 amplitude seem to be associated with incorrect responses. However, more evidence is needed to confirm this argument.

CHAPTER 6

EXPERIMENT 4: P300 AND EVALUATION

6.1. Introduction

McCarthy and Donchin (1981) suggested that the P300 latency may indicate the completion of stimulus evaluation. In the previous experiments, P300 latency correlated positively with inspection time, but the correlations were not significant. To further explore the relation between inspection time and P300 latency another type of IT presentation is to be employed in this experiment.

The proposed paradigm of IT presentation has been discussed by Salthouse (1985). It is different in two aspects from the most commonly used IT paradigm (i.e. Vickers' (1972) paradigm). First, instead of varying the exposure duration of the discriminative stimulus in each trial of the IT task, this paradigm uses a fixed brief exposure duration for the display of the discriminative stimulus. This fixed brief exposure duration of the discriminative stimulus is identical for all subjects. Second, the backward mask does not immediately replace the discriminative stimulus after that fixed exposure duration. There is a blank gap following the discriminative stimulus. The mask appears after that blank gap. For each trial, the delay between the stimulus offset and the mask onset depends upon subjects' performance on the task (Saccuzzo *et al.* 1979, 1986; Salthouse, 1985). Because a subject's IT estimate is expressed in this paradigm by the blank gap between the offset of the discriminative stimulus and the onset of the mask figure, this type of IT presentation will be called as the Gap IT task in this thesis.

Salthouse (1985) has described some theoretical considerations for the Gap IT task. In the standard IT task (Vickers *et al.* 1972), the encoding or uptake of sensory information is technically assumed to continue until the time when the mask replaces the discriminative stimulus (Saccuzzo *et al.* 1979). The amount of information available to be encoded into STM during the time of the discriminative stimulus exposure is different from one subject to another. It varies as a function of the exposure duration of the discriminative stimulus. By presenting the display of the discriminative stimulus for a very short and fixed duration and by varying the time interval between the offset of the discriminative stimulus and the onset of the mask, it is assumed that the amount of sensory information (i.e. the icon) available for sampling may be the same for every subject, and that subjects encode sensory information from the icon. As the amount of sensory information provided by the icon is limited in the first place in the Gap IT paradigm, subjects have to put in more effort to evaluate, or use, encoded information as thoroughly as possible so that they can make the best out of the limited amount of information. Therefore, it is thought that this paradigm may be able to highlight the evaluation aspect of information processing involved in the IT task (Salthouse, 1985).

With the above discussions in mind, we may expect in this experiment that: 1) the correlation between the Gap IT measure and the P300 latency might be stand out more clearly; and 2) the correlations between the Gap IT scores and the temporal measures of the P200 component would no longer be conspicuous, because the process of encoding in the Gap IT paradigm may not be as crucial as it is in the standard IT paradigm.

The second aim of this experiment is to explore the relation between subjects' performance on the task and the process of their attention for, or anticipation of, the task stimulus, as some studies suggest that under some circumstances subjects' anticipation can be important with respect to their performance on tasks similar to the inspection time (Morrison, 1982). To measure the strength of subjects' anticipation of the impending discriminative stimulus after a cue signal, contingent negative variation (CNV), which indexes one's expectancy of an impending stimulus (Walter *et al.* 1964; Cohen, 1974; Empson, 1986), is to be monitored in the present experiment. Studies of CNV activity indicate that the CNV amplitude is positively related to the strength of anticipation (Tecce, 1971). It seems reasonable to predict that the CNV amplitude will correlate negatively with the IT measure if it is assumed that a strong anticipation would benefit subjects' performance on the task (Morrison, 1982).

6.2. Methods

1) Subjects. 20 second-year Psychology undergraduates participated in this experiment. The mean age of this group was 20.3 years with the S.D. being 1.7 years. Subjects had normal or corrected-to-normal vision.

2) Stimuli. Test stimuli were the same as in Experiment 3, except that the exposure duration of the discriminative stimulus was fixed at 10 msec and the mask was presented after a delay (Salthouse, 1985) (Diagram 6.1). The delay time varied as a function of subjects' performance on the task. The cue signal was the horizontal bar (18mm long) which had been used in the pilot study and the first two experiments. In this experiment, the cue occurred 1800 msec before the onset of the test stimulus and lasted for 300 msec, giving a 1500 msec cue-stimulus interval (Diagram 6.1).

Subjects were instructed to make their judgments by pressing one of the

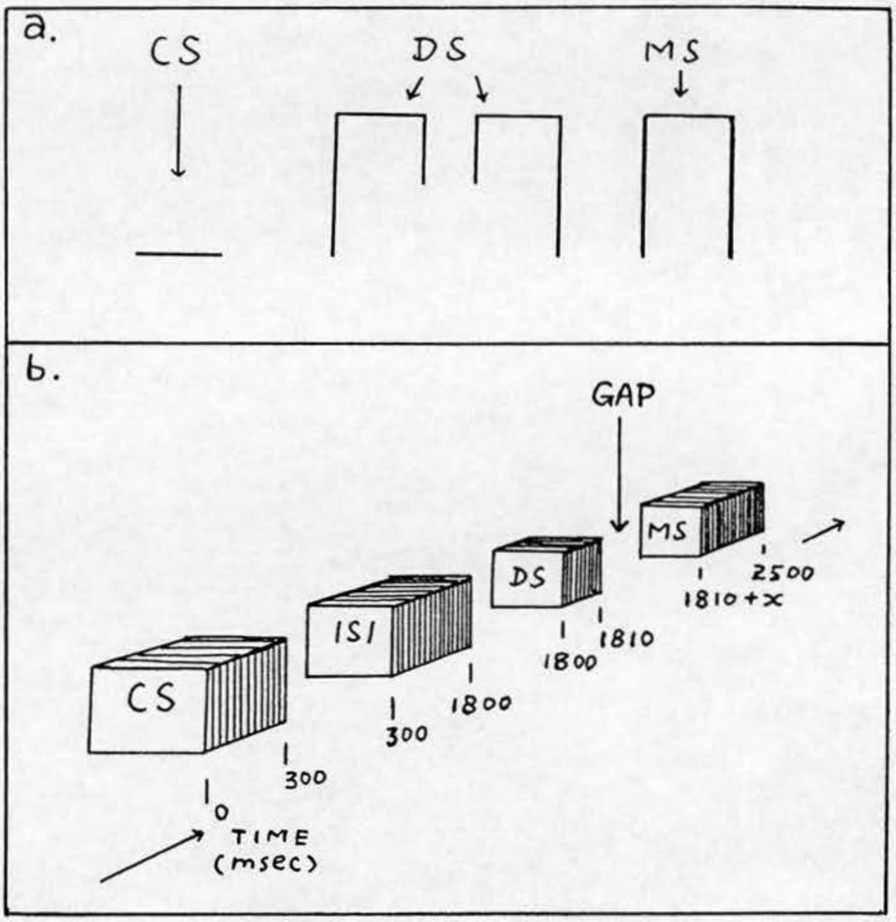

Diagram 6.1

Diagram 6.1a shows the patterns of stimuli used. Diagram 6.1b outlines the procedure. CS: cue signal; ISI: inter-stimulus interval; DS: discriminative stimulus; MS: backward mask.

two levers. All of them were required to respond to the longer line in the display of the discriminative stimulus, and they were also told not to make the response until the mask was off. The order of presentation of the two discriminative stimuli (Long-Left or Long-Right) was randomized, and the post-response interval varied randomly over the range of 2-3 seconds.

3) ERP data recording. The recording system and electrode placement remained as before. Sampling epoch was 1024 msec. In order to see whether there existed any relation between CNV activity and IT measures, the sampling started 400 msec before the onset of the discriminative stimulus. 200 ERPs were obtained from each subject while his/her Gap IT was being tested. In order to continue the sampling till the 200 recordings were collected, the delay time between the offset of the discriminative stimulus and the onset of the mask figure was fixed at the subject's Gap IT estimate for the rest of the trials as soon as his/her Gap IT was determined.

4) Procedure. Subjects had a practice session on the task before the electrodes were attached to their heads. The resistances were monitored before and after recording. The average resistance was 5.78 Kohm with the S.D. being 1.00 Kohm. They, then, moved on to the formal session of the Gap IT estimation. A computer program written according to the PEST (Taylor & Creelman, 1967) was used for the Gap IT estimation. The Gap IT measure was defined as the minimum delay time before the mask onset which was required to make 90% correct responses. The whole run for each subject could be completed within one hour.

Subjects' intellectual ability was measured using Raven's Advanced Progressive Matrices (RAPM). 18 subjects were IQ tested in a group situation (during the attendance of one of the class practicals in the Department) one month before their ERPs were recorded.

The AEP measures used in this experiment were as follows: a) latency measures of P200 and P300 components; b) $P200_T$ measure based on the 75-275 msec window analysis; c) a measure of CNV (average amplitude over the 50 msec epoch preceding the time at which the eliciting stimulus occurred, relative to the zero level of the recording system).

6.3. Results and discussion

Only 17 subjects' ERP data was available for analysis. Raw ERP data from the rest of the subjects was lost, due to a fault in the University computer system, while in store prior to analysis. The reported results were calculated from these 17 subjects' data. Out of 17, 15 subjects had RAPM scores available. The mean RAPM score was 24.73 with the S.D. being 3.20.

Fig. 6.1 shows the averaged response of one subject and the grand mean of the 17 subjects. In this experiment, averaging started from the fourth ERP recording and the AEP for each subject was summated using 190 samples. Fig. 6.1 revealed that there was a distinct CNV component when subjects were performing the task, indicating that subjects were anticipating the test stimuli as was expected.

Table 6.1 contains the means and standard deviations of the AEP parameters concerned and the Gap IT estimate. Correlations between AEP measures, Gap IT estimates and RAPM scores are shown in Table 6.2. The partial correlations, when the CNV amplitude was controlled, are given in Table 6.3.

Average evoked potentials

Sampling rate of display: 200Hz.

(a) for one subject

(b) the grand mean

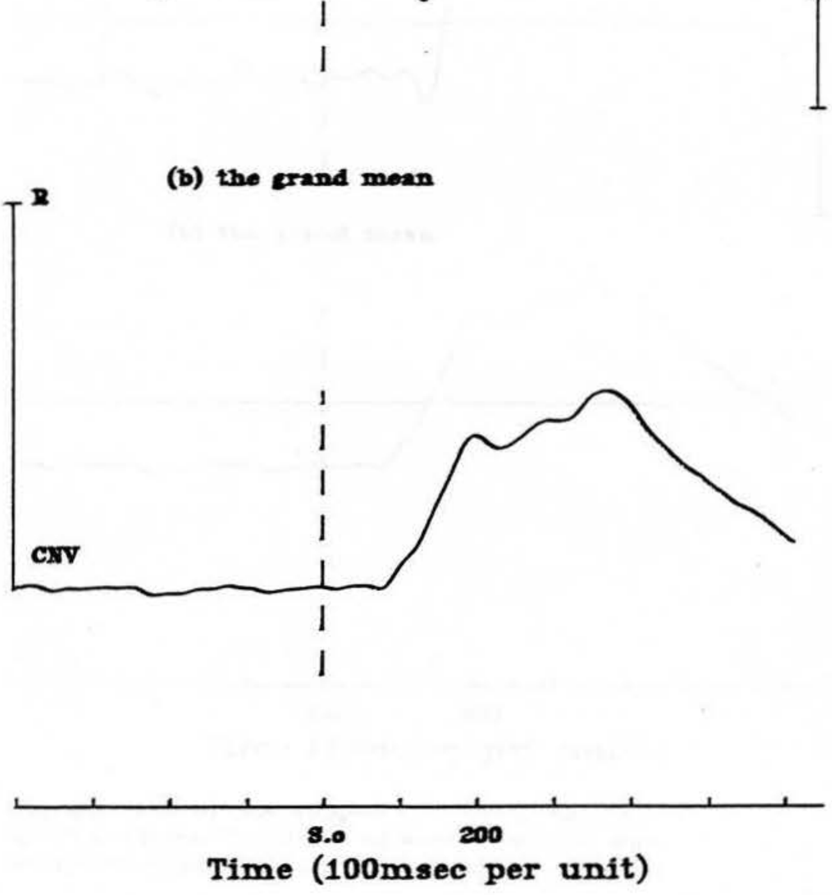

Fig. 6.1 AEP of one subject and the grand mean of 17 subjects. Positivity upwards. Dashed line: stimulus onset. R: the zero level of the recording system.

Table 6.1
Means and standard deviations of Gap IT and AEP measures

	Mean	S.D.
Gap IT	21.41	9.59
P200$_L$	196.55	19.65
P300$_L$	347.55	35.85
P200$_T$	36.90	11.15
CNV amplitude(μV)	17.54	1.56

Note: unit in msec, or otherwise stated; larger CNV amplitude represents greater negativity.

Table 6.2
Correlations between relevant measures

	Gap IT	RAPM	CNV
RAPM	-.17		
CNV	.44*	-.23	
P200$_L$	.00	-.11	-.21
P300$_L$	.08	-.07	-.17
P200$_T$	-.03	-.33	-.28

* $P<.05$, one-tailed.

Table 6.3
Correlations after partialling out CNV

	Gap IT	RAPM
RAPM	-.08	
P200$_L$	.11	-.17
P300$_L$	.18	-.11
P200$_T$	.11	-.42

6.3.1. Role of anticipation in the IT task

The CNV component was very distinct in Fig. 6.1, indicating that subjects were paying close attention to the task. Contrary to the prediction, the CNV amplitude correlated positively with the Gap IT score (r=.44, n=17) This correlation would be significant at the 0.05 level on an one-tailed test, suggesting that strong anticipation might have impaired rather than facilitated subjects' performance on this task.

How might this finding be explained? The reason might lie in the length of the warning period (1800 msec) used in this experiment, that is, the period from the onset of the cue signal to that of the discriminative stimulus. During the time of the warning period, subjects need to maintain their anticipation or preparedness for the impending task stimulus to which they must respond. As the warning period was fixed at 1800 msec in this experiment, its effect on the maintenance of the preparedness might have been responsible for the above finding. In a study of alertness, Morrison (1982) asked subjects to identify a single geometric form under backward masking conditions at varying warning intervals. One item at a time was presented to subjects for identification and no speeded response (reaction time) was required. In an attempt to compare levels of performance as a function of hypothesized levels of alertness, Morrison divided warning intervals into three groups: preoptimal level (150 msec and 300 msec), optimal level (500 msec and 750 msec), and postoptimal level (1500 msec and 2000 msec). As the author predicted, the performance varied as a function of the warning interval (F(2,36)=20.1, p<.001). Specific comparisons disclosed that for adults no change in the performance occurred from the 'preoptimal' to the 'optimal' interval (t=1.2, df=36, N.S.). A significant decrease in performance was found between the 'optimal' interval and 'postoptimal' interval (t=2.1, df=36, p<.05). No difference was observed comparing 'preoptimal' with 'postoptimal' alertness levels ($t < 1.0$, $df=36$). Hence, Morrison concluded that decrease in levels of alertness occurred in the 'postoptimal' intervals, i.e. the intervals of either 1500 msec or 2000 msec between a warning signal and a stimulus signal.

The difference between Morrison's suggestion and the IT-CNV correlation observed in the present experiment is that in the former a poor performance was assumed to be associated with the decrease in the level of alertness, whereas in the latter the poor performance was found to correlate with strong anticipation, indexed by the amplitude of the CNV component (Tecce, 1971). Since no CNV measure was used in Morrison's study, we do not know whether or not the three hypothesized levels of alertness would decrease as the warning interval increased. Perhaps, it was in fact the other way around.

Tecce (1971) suggested that the CNV amplitude appears to be positively and monotonically related to the process of attention. Therefore, the positive correlation found in this experiment between the CNV amplitude and the GAP IT measure implied that subjects' performance on the IT task might improve with increased attention up to an optimum level, and become impaired with the continuous effort of maintaining attention at a high level, due to a long warning interval. In other words, the relationship between attention and performance on the IT task might be similar to that between arousal and performance (Lefrancois, 1980, pp. 311-312). To maintain attention at a high level for a long time may compete for resources with other stages of information processing, such as the encoding and evaluation, and influence the performance towards an undesired direction. Whatever the explanation might be, the IT-CNV relation should at least have brought to our attention the role of anticipation in IT task performance.

6.3.2. Gap IT and the other AEP measures

As expected, the Gap IT did not correlate this time with the temporal measures of the P200 component (i.e. $P200_L$ and $P200_T$).

In contrast with the mean P300 latencies (about 330 msec) obtained in the previous experiments, the mean P300 latency appeared to have increased considerably in this experiment (347.95 msec), which was in favour of the idea described earlier, i.e. with a fixed and brief exposure of the discriminative stimulus the importance of the evaluation of the encoded information in the IT task may be highlighted (Salthouse, 1985). However, the correlation between P300 latency and Gap IT did not offer any direct evidence for the argument that the IT measure is related significantly to the P300 component ($r=.18$, $df=14$, n.s. after partialling out CNV) (Tables 6.2 and 6.3). The results suggested merely that the P300 component may indicate the completion of evaluation (McCarthy & Donchin, 1981), rather than reflecting the process per se.

6.3.3. Evidence for 'strategy theory'

To further examine the 'strategy theory' described previously, stepwise discriminant analysis was also performed on the data from this experiment (BMDP7M, Dixon, 1983). The rationale for this analysis and the details of how it was carried out are the same as explained in Section 5.3.4. In the present experiment, each smoothed ERP trace had 101 time points, which represented a 1000 msec epoch of ERP recording. Originally, it was thought that 200 samples recorded from each subject could satisfy the requirement of the minimum 64 recordings for each average after they were divided into two groups, 'correct' and 'wrong'. Because the existing BMDP7M procedure is not capable of handling more than 100 cases by 100 variables at a time, only half of the samples (those tagged with an odd number) were used in the analysis.

The mean percentage of correct classification by the stepwise discriminant analysis was 77.1% for the 'correct' group, 75.6% for the 'wrong' group and 77.0% for the total. Fig. 6.2 depicts the mean traces for the two groups. The responses starting from the stimulus onset were quite similar to those in Fig. 5.2, indicating by the P300 latency that subjects tend to give up a trial as soon as possible if they perceive that it is impossible to make a discrimination and, consequently, they fail on that trial. Measuring the P300 latencies for the two groups separately, it was found that the mean latency was 346.30 msec (S.D.=38.20) for the 'correct' and 335.05 msec (S.D.=41.60) for the 'wrong'. A Wilcoxon test revealed the 11.25 msec difference was significant (T=34.5, N=16, $p<.05$ for one-tailed test).

Fig. 6.2 also seems to suggest that the P200 component peaked later for the 'wrong' than for the 'correct' responses (also see Fig. 5.2). The mean latency of the P200 component was 200.95 msec (S.D.=18.00) for the 'wrong' responses, and 189.10 msec (S.D.=20.95) for the 'correct' responses. The 11.85 msec difference between them was also statistically significant (Wilcoxon T=3.5, N=15, $p<.01$ for two-tailed test). This finding may be interpreted as showing that subjects continued to accumulate sensory evidence even after the information had been contaminated by the onset of the mask on a trial. They then failed because there was not enough uncontaminated information available in STM for them to make a judgment (Smith, 1986). Perhaps the state of anticipation was one of the causes which brought them troubles when sensory information was due to be encoded.

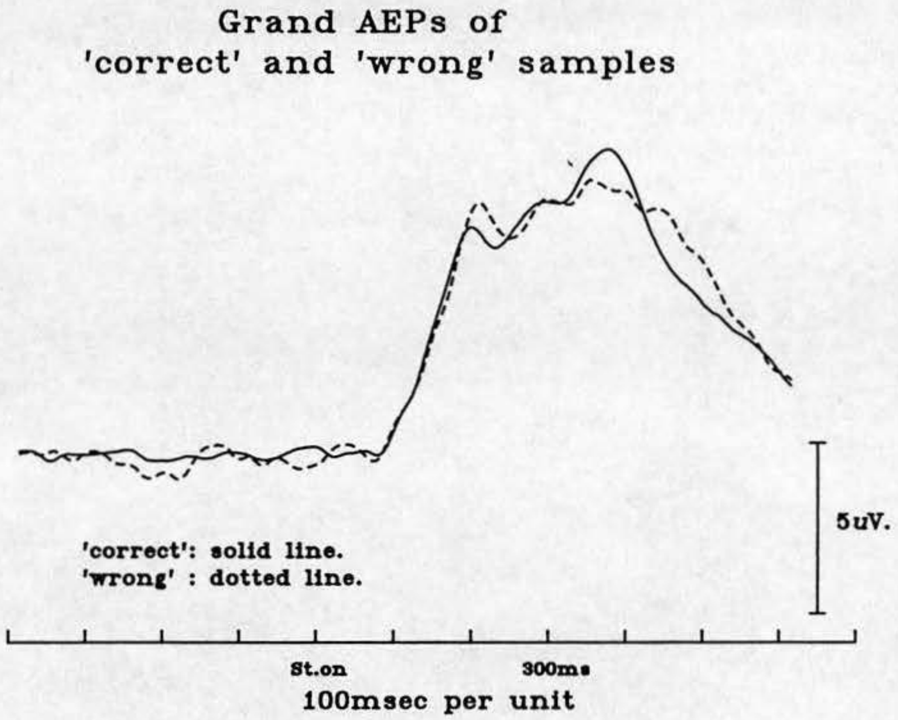

Fig. 6.2 Average of the 'correct' group and average of the 'wrong' group. The two groups were classified by discriminant analysis. Data was from 17 subjects. Positivity upwards.

6.3.4. IQ-AEP relation

No significant correlations were found between RAPM scores and AEP measures, either before or after partialling out the CNV measure. However, all correlations were in the expected direction with the IQ-$P200_T$ correlation being close to significance ($r=-.42$, $df=12$, $p<.07$, one-tailed) (Table 6.3).

6.4. Summary

In this experiment, one attempt was made to fix the amount of sensory information available to subjects with the intention of highlighting the evaluation aspect of information processing in the IT task. Although the results did agree statistically with the 'strategy theory', there was no direct evidence to support the hypothesis that the P300 latency reflects the process of discrimination or evaluation per se.

A positive correlation was found between the Gap IT measure and the amplitude of the CNV component, suggesting that under the present conditions the role of anticipation, as indexed by CNV amplitude, may be also important in the IT task. So far this issue has not been addressed empirically in studies of inspection time.

CHAPTER 7

EXPERIMENT 5: THE EFFECT OF ANTICIPATION ON THE IT

7.1. Introduction

In the last experiment it was found that the CNV amplitude correlated significantly with the Gap IT measure (r=.44, p<.05). The implication of this finding is that under some circumstances the process of anticipation, indexed by the CNV amplitude, may also play an important role in subjects' performance on an ordinary IT task. This experiment aimed to investigate whether the IT-CNV relation could be observed in the ordinary IT situation.

7.2. Methods

1) Subjects. Ten teenagers from a local secondary school participated in this experiment. The mean age of this group was 15.90 years with the S.D. being 0.74 years.

2) Stimuli. The ordinary IT paradigm was used in this experiment, i.e. the exposure duration of the discriminative stimulus followed immediately by a backward mask varies as a function of subjects' performance on the task. Test stimuli were the same as described in Exp. 3 (see Section 5.2) (Diagram 7.1). The cue signal was the horizontal bar (18mm long) used previously in the pilot study, and in Exp. 1, 2, and 4. As in the last experiment, the cue signal was presented 1800 msec before the onset of the task stimulus, and lasted for 300 msec (Diagram 7.1).

The display was viewed from an easy reach distance and subjects were

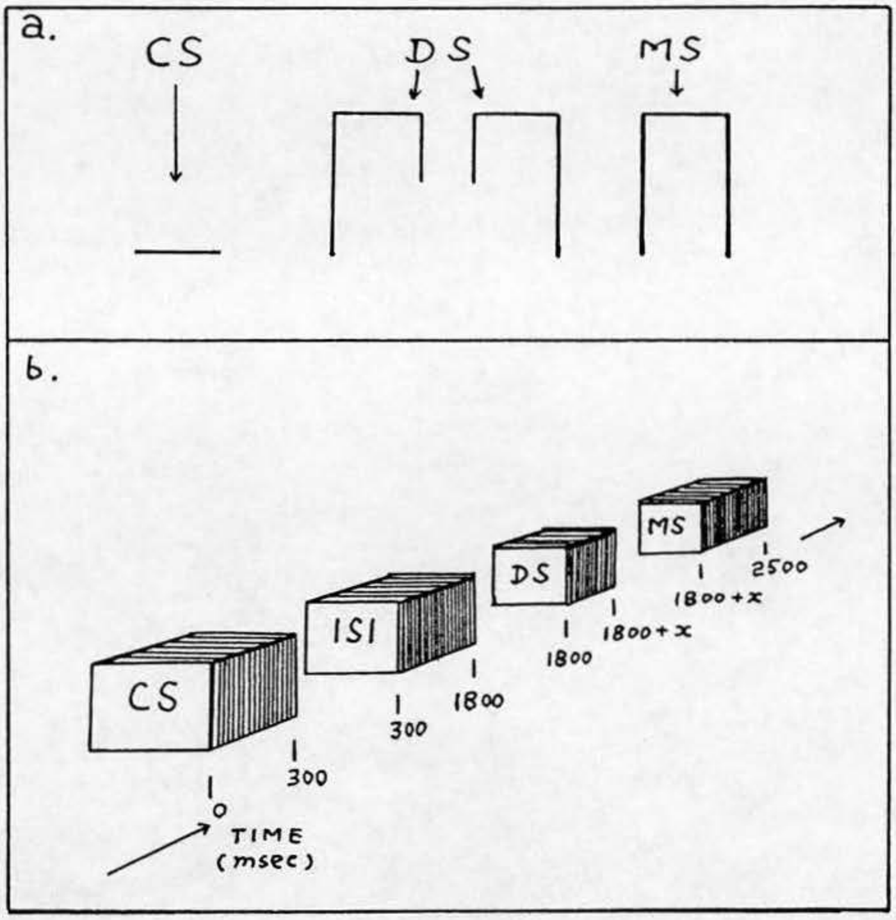

Diagram 7.1

Diagram 7.1a shows the patterns of stimuli used. Diagram 7.1b outlines the procedure. CS: cue signal; ISI: inter-stimulus interval; DS: discriminative stimulus; MS: backward mask.

invited to make their judgments by pressing one of the two levers. All subjects were required to respond to the long vertical line. They were instructed not to press the lever until the mask was off. The order of presentation of the discriminative stimuli (Long-Left or Long-Right) was randomized. The post-response interval varied randomly over the range of 2-3 seconds.

3) ERP data recording. The recording arrangement and electrode placement remained as before. Sampling epoch was 1024 msec, starting 400 msec before the stimulus onset. 100 samples were obtained from each subject while his/her IT score was being tested. In order to continue the sampling till the 100 samples were collected, the subject's IT-type stimulus was used for the rest of trials as soon as his/her IT was determined.

4) Procedure. As before, subjects began with a practice session. Electrodes were then placed on their heads. Finally, they did the IT task and their ERPs were recorded at the same time. The mean resistance was 5.14 Kohm with the S.D. being 1.98 Kohm. The IT measure was defined as the minimum stimulus exposure duration required to make 85% correct responses.

7.3. Results

Fig. 7.1 depicts the average of the first 90 samples of one subject, and the grand mean of the 10 subjects' data. The CNV component was distinct, as in the last experiment. It appeared that the P200 component consisted of a double peak in the present experiment, which caused difficulties in scoring the $P200_T$ measure of the 75-275 msec window analysis for some subjects. Therefore, only three AEP measures were taken this time, which included the latencies of the P200 and P300 components, and the CNV measure. The CNV

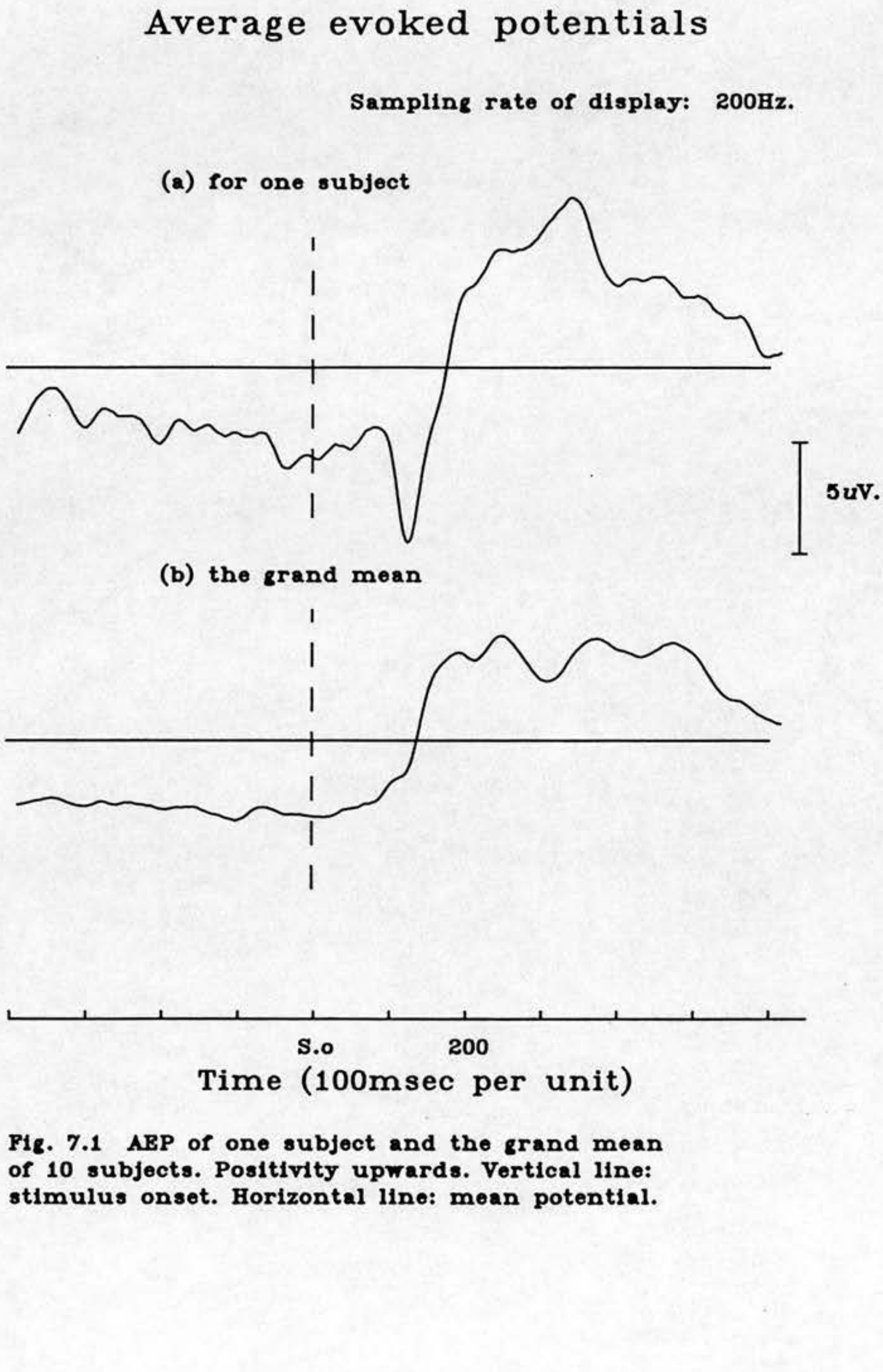

Fig. 7.1 AEP of one subject and the grand mean of 10 subjects. Positivity upwards. Vertical line: stimulus onset. Horizontal line: mean potential.

measure was the average amplitude over the 400 msec prestimulus epoch relative to the zero level of the recording system.

Table 7.1 contains the means and standard deviations of the measures concerned. Correlations among them are given in Table 7.2.

Table 7.1
Means and standard deviations of measures concerned

	Mean	S.D.
IT	25.50	6.98
CNV(μV)	17.97	0.93
$P200_L$	204.60	30.55
$P300_L$	346.85	39.45

Note: unit in msec, or otherwise stated; larger CNV measures represent greater negativity.

Table 7.2
Correlations between relevant measures

(N=10)	CNV	$P200_L$	$P300_L$
IT	$.58^*$	-.08	.37
CNV		$.61^*$	-.25

* p<.05, one-tailed.

7.4. Discussion

7.4.1. Effect of anticipation on IT measure

It was found that the CNV measure correlated significantly with the standard IT score (r=.58, n=10, p<.05, one-tailed), which confirmed the finding observed in the last experiment using Gap-IT and indicated that under some circumstances the process of anticipation does play an important role in subjects' performance on the IT task (Morrison, 1982). To be more specific, I would like to suggest that the effect of anticipation on the IT task performance may be attributable to a state of over-anticipation among some subjects. The state of over-anticipation which occurs due to a long and regular warning period (1800 msec in this case) may handicap subjects' performance on the IT task. Their relation may be just like the well-known relationship between arousal and performance (Lefrancois, 1980, pp. 311-312).

Suppose that the P200 component reflects the process of information encoding, the above interpretation is consistent with the positive correlation revealed here between the P200 latency and the CNV measure (r=.61, n=10, p<.05, one-tailed) (Table 7.2), which indicates that the value of the latency of the P200 component was larger when subjects' anticipation was strong (Lehtonen, 1973). The implication of this observation was that because of their efforts of maintaining anticipation at a high level, indexed by the prolonged CNV activity, subjects needed to spend longer on the following process of encoding. As a result, they did not do well on the task. However, this explanation raises a question: if it was the case, why did the P200 latency not correlate *positively* with subjects' IT score (r=-.08) (Table 7.2)? A possible answer to this question is suggested in the next section.

7.4.2. A 'second look' hypothesis?

As mentioned earlier, the P200 component consisted of a double peak in this experiment (Fig. 7.1). I think this 'double peak' phenomenon might also be attributable to the prolonged CNV activity. Suppose that in situations in which the warning period is relatively short (500 msec in Experiments 1, 2 and 3), one encoding event or sample may enable subjects to take up enough sensory information for them to make a decision. Therefore, only one P200 peak will occur in these situations, given that the P200 component reflects the process of encoding. In other situations, where the warning period is long (1800 msec in this experiment), subjects need to put in more effort to maintain their anticipation of a task stimulus at a high level. This may compete with the following process of encoding for resources. In these situations, the first encoding may be unable to take up enough information for subjects to make a decision, and they have to resort to a second encoding, or 'second look', to get more information into STM so that they can make a correct response or an ultimate decision. Consequently, a double peak of the P200 may occur, with its first peak reflecting the first encoding and its second peak the second encoding.

This hypothesis, called 'second look' hypothesis, is consistent with observations in the literature. It appears that a second, or a third, or even more, positive peaks are likely to occur after the first positive peak (usually defined as the P200) and before the occurrence of the distinct P300 if there is a need for subjects to encode information continuously or when a task is of sufficient complexity (Squires, N.K. *et al.* 1975; Hillyard, 1984; Kutas & Hillyard, 1984; Stuss *et al.* 1984). Adam & Collins (1978) investigated the changes of visual ERPs as a function of the amount of search in STM, using Sternberg's (1966) memory search paradigm. There were six sizes of memory set, which were 1, 3, 5, 7, 9 and 11. In each trial subjects saw a series of digits (set) followed by a target digit (TD). In 50% of trials the TD was included in the set, and in 50% it was not. Visual ERPs to the TD were recorded. It was noted that up to three positive peaks occurred in a row in the range of 140 msec to 300 msec before the occurrence of the P300 component. For the set size 1 or 3, only one positive peak with a latency of about 140 msec, which was defined as the P200 component, occurred before the P300 component. For set size 5, two positive peaks occurred before the P300, one having a latency of 140 msec and the other a latency of about 240 msec. For the rest of the set sizes (7, 9 and 11), three positive peaks were identified in the range of 140 msec to 300 msec before the occurrence of the P300, and the third peak had a latency of about 270 msec. It appears that subjects needed to encode more information into STM, and this was reflected by the second (and third) positive peak identified, as the amount of searching increased. The overall process seemed to work in the following manner: 'encoding - evaluation - encoding - evaluation - ...' (Vickers & Smith, 1986). It terminated when a decision was made, which was reflected by the occurrence of the P300 component. In the study done by McCarthy and Donchin (1981), which was detailed in Section 3.1, a third positive peak, which occurred between the P200 and P300 components, could also be identified under the 'noise' condition. This peak reached a maximum at about 360 msec from the stimulus onset. In contrast, under the 'no noise' condition the P200 component was followed immediately by the P300 component, which peaked at about 360 msec (also see McCarthy, 1980). Thus, it seemed that subjects in McCarthy and Donchin's study had to take a 'second look' (encoding) under the 'noise' condition, as might be expected; and the 'second look' was indexed by the positive peak occurring between the P200 and P300 components.

On the other hand, as it has been suggested that the P300 component indicates the termination of evaluation (Adam & Collins, 1978; McCarthy & Donchin, 1981), it may be suspected that the positive peak which occurs immediately before the P300 component might be more sensitive to the overall process of 'encoding - evaluation - encoding - evaluation - ...'. This was examined using the AEP data of the present experiment. The latency of the second peak of the double-peak complex, if it could be identified, was taken for individual subjects and related to their IT measure. The mean of this new latency measure ($P200_L'$) was 234.5 msec (S.D.=26.0 msec). The latency value was 29.9 msec longer than that of the $P200_L$ (204.60 msec, Table 7.1), which was measured from the maximum peak within the range of 150 msec to 250 msec. It was found that the $P200_L'$ correlated *positively* with the IT measure (r=.33, n=10). Although the correlation did not achieve significance, this did provide evidence in favour of the 'second look' hypothesis, and indicated a possible answer to the question raised at the end of the last section.

CHAPTER 8

INTERMEDIATE DISCUSSION

8.1. AEP components in IT task

In the experiments completed so far, three evoked potential components appear to be important indicators of a relationship between IT and ERPs. The three components are the P200 component, the P300 component and the CNV component.

8.1.1. The P200 component

As discussed in Chapter 3, some authors have reported that the P200 component is absent when an external stimulus is missing (Barlow *et al.* 1965; Klinke *et al.* 1968; Picton & Hillyard, 1974; Armington, 1981). This observation has been quite consistent. For instance, in a study of the visual omission response in a reaction time situation Renault & Lesevre (1979) asked seven normal subjects to give, as quickly as possible, a motor response whenever a visual stimulus was missing. Evoked responses to omitted stimuli were obtained during the testing in which 450 visual stimuli were delivered at a rate of one per second. Ten percent of the stimuli were omitted randomly. It was found that the average response to the missing stimulus was made up of a negative component with a latency of 265 msec beginning in the parieto-occipital region and peaking later towards the vertex. This was followed by two positive components, the first one with a latency of 383 msec peaking at the vertex and the second with a latency of about 508 msec peaking in the parieto-occipital region.

The fact that the P200 component may not be observed in the task-oriented situation when the external stimulus is absent indicates that the process which is responsible for producing P200 component may have something to do with the availability of the sensory information to be encoded (Chapman *et al.* 1978). The results obtained in Exp. 1 and 2 were consistent with this suggestion. The P200 component appeared identical under different eliciting conditions, suggesting that it may have indexed an initial operation of information processing, which was identical no matter where the sensory information encoded into STM came from (i.e. the IT-type, or the non-masked, or the mask-only stimulus).

Apparently, there existed two components of information processing that should not be subject to the effects of variation in task difficulty, which was a variable in Exp. 1 and 2. One of them was the process of anticipation and the other was the process of encoding sensory information from iconic storage into STM. Together with the fact that an external stimulus is essential for the occurrence of the P200 component, the significant positive correlations between IT estimates and the temporal measures of P200 component found in the first three experiments provided evidence supporting the interpretation that the P200 reflects the process of encoding (Chapman *et al.* 1978). This interpretation is also consistent with the assumption that the vertex potential reflects some neural and/or psychological operation (Picton & Hink, 1974; Hillyard & Woods, 1979).

It may be important to note explicitly that some studies have presented evidence which appears contradictory to the above proposition. In a study by Shevrin and Fritzler (1968), two stimuli (one meaningful and the other vague) were presented separately to subjects for 0.001 sec. Although the exposure duration of stimuli was too short to permit conscious discrimination of the stimuli, it was found that the two stimuli evoked different AEPs. The difference occurred for the N150-P200 complex recorded at the vertex. It was larger for the meaningful stimulus than for the vague stimulus. The change was correlated with the verbal report of subjects' free association in a perceptual level. The study thus claimed that the positive-going component of the AEP, with an initial latency of 160-250 msec, discriminated between the two stimuli although these could not be discriminated behaviourally by subjects (Shevrin *et al.* 1971).

A strong criticism of this view came from Schwartz (1976). Schwartz presented Shevrin's two stimuli in the same trials to his subjects, and simply asked them whether the stimuli were the same or different. That is, designating the stimuli as R and A, there were four types of trials in a block, R-R, R-A, A-R and A-A. Over blocks of trials, exposure duration was increased so that accuracy of the discrimination increased. In comparing differences in AEPs across exposure durations, the changes in AEPs could be examined in relation to discrimination performance. The results of the study showed that the positive component identified by Shevrin did not differentiate the two stimuli at any exposure duration in any way that was related to discrimination performance, which led to the conclusion that the AEP component represented general operations, not the specific content of the information being processed.

Under the hypothesis that the P200 component reflects the process of sensory information encoding, however, these conflicting observations may be integrated with one another. For instance, in Shevrin's study the two stimuli were presented separately, and subjects might have encoded more information during the 0.001 sec exposure duration when the stimulus was meaningful or psychologically organized than that when the stimulus was vague. Consequently, the AEP to the meaningful stimulus showed a larger P200 amplitude. Whereas in Schwartz's study, two stimuli were presented at the same time in each trial and subjects were merely asked to say whether they were the same or different. From the subjects' point of view, all of four types of trials could have been 'meaningful', i.e. either the same or different. Therefore, no difference between the P200 amplitudes of AEPs should have been expected.

On the other hand, Shevrin's finding implies that if the process of encoding is indexed by the P200 component, that process seems more likely to be dynamic in terms of its relationships with other stages of information processing. For instance, the process of evaluating the encoded stimulus may begin while information is being encoded, and the amount of information being encoded may depend upon the progress of the process of stimulus evaluation (Squires, K.C. *et al.* 1976). Therefore, the more meaningful the encoded information was, and the more information would have been taken in. For instance, Sheatz & Chapman (1969) reported that the amplitude of the P200 component was larger for the relevant stimulus in an auditory task than for the irrelevant stimulus, and the difference was significant ($F(1,8)=29.44$, $p<.001$). Donchin & Lindsley (1966) recorded vertex evoked potentials to brief light flashes from ten subjects during a reaction time task. Subjects performed under two conditions, with and without feedback. It was found that the P200 amplitude was related to reaction time. For any given sequence of reaction time, faster reactions were associated with larger amplitudes of the P200 component. Knowledge of results shortened reaction time and increased the magnitude of the component.

However, it may be a little early to conclude that the P200 component indeed reflects the process of sensory information encoding, because some have argued that the increase in amplitude of the P200 component reported in the studies mentioned above might have been a differential preparation artifact (Satterfield, 1965; Donchin & Lindsley, 1966; Sheatz & Chapman, 1969; Karlin, 1970). What we need at this stage seems to be an experiment that is similar to Exp. 1 and 2, and that provides the measures of the CNV activity as well as that of the P200 component. If the IT-P200 relation is observed in this experiment and no relation is found between the IT and CNV measures, we should be able to conclude that the P200 hypothesis holds true at least partially.

8.1.2. The P300 component

Ruchkin *et al.* (1980b) provided evidence indicating that the P300 component becomes smaller as accuracy of response decreases. Six adult subjects participated in Ruchkin's study. Their task was to detect auditory signals. Each trial was initiated by an experimenter after the subject reported being ready. A warning click was followed by a 700 msec interval at the end of which a second click, whose presence or absence was to be detected, was presented in 50% of the trials. The clicks were delivered monaurally to the right ear through a headphone set driven by a square pulse whose duration was 0.12 msec. The first click for all trials was at approximately 25dB sensation level. On a given block of trials one of 3 intensities (Lo, Mid, or Hi) was used for the second click (when it was presented). The 3 intensities were adjusted separately for each subject so that the presence of the second click could be detected with accuracies of about 63%(Lo), 87%(Mid), and 99%(Hi). A fixation light offset occurring 2.5 sec after the initial click indicated to subjects that a trial was over. Following fixation light offset, the subject reported whether the trial consisted of a single or double click and his degree of confidence (high or low) in his decision. No feedback concerning correctness of response was given during the testing. Evoked potentials were recorded from the vertex and the other positions with the reference electrode being placed on the left earlobe and the ground electrode on the right earlobe. It was found that the amplitude of the P300 component increased with increasing accuracy from about 63% to 99% ($p<.01$). Using principal components analysis, it was again evident that as accuracy increased from 63% to 99% for both hits and correct rejections the factor scores of the P300 amplitude increased, and the main effect of accuracy for P300 amplitude was significant ($p<.005$). These findings indicated that the P300 component became smaller as accuracy decreased, i.e. as the amount of information provided by an event diminished.

The results obtained in Exp. 1 and 2 were remarkably similar to Ruchkin's findings. The P300 amplitude was significantly affected by the levels of task difficulty. The easiest task condition evoked the largest amplitude, with the medium level next and the hardest condition the smallest (Page's trend test $L(3,8)=105$, $p<.05$ for one-tailed test). When the ERPs were classified into 'correct' or 'incorrect' groups in Exp. 3 and 4, the P300 amplitude was larger for the 'correct' than for the 'incorrect' responses. Therefore, it seems clear that the P300 amplitude is related to subjects' confidence in their task performance or the evaluation of their performance (Hillyard, 1971; Squires, K.C. *et al.* 1973; Kutas *et al.* 1977; Polich, 1986).

However, the present experiments did not provide any statistically significant correlations between inspection time and P300 latency, but the correlations were all positive and suggested that the P300 latency may indicate the completion or termination of the cognitive evaluation of information (Adam & Collins, 1978; McCarthy & Donchin, 1981), rather than the evaluation per se.

8.1.3. The CNV component

It was found in Exp. 4 and 5 that the measure of CNV amplitude correlated positively with inspection time ($p<.05$), suggesting that subjects' anticipation during the testing, which was indexed by the CNV amplitude, might play an important part in their task performance under some circumstances (Morrison, 1982; Michie, 1984). It appeared that in the situations in which the warning period was fixed at 1800 msec, strong anticipation was associated with a poor performance on the IT task. Perhaps this IT-CNV relationship was caused by resource competition between anticipation during a long and regular warning period and the subsequent process of encoding. As a result, a strong (or over-) anticipation was associated with poor performance on the IT task, where the process of encoding may have played the most crucial part in terms of task performance.

At this stage, it is too early to draw any conclusions on the relationship between the CNV and IT measures. Nevertheless, these findings indicate that the effect of anticipation or attention on the performance of the IT task should be examined in future investigations of inspection time. The description of what the inspection time measure indexes may also need to include the role of anticipation, at least, under some circumstances. Certainly, we need to know whether or not the IT-CNV relation can be observed when the warning period is fixed at a short duration; for example, the 500 msec period used in Exp. 1, 2 and 3.

8.2. A model for inspection time

The characteristics of the P200 component recorded at the vertex in the IT task situation in the previous experiments of this study, and the correlations between P200 and IT measures are consistent with the assumption that inspection time either estimates the rate of sampling of sensory input in the initial stages of information processing (Vickers *et al.* 1972) or reflects the speed of information intake (Brand & Deary, 1982). The findings that the P300 amplitude increased as the task difficulty decreased or when subjects were going to release a 'correct' response, and that the P300 latency correlated consistently and positively with inspection time, indicate that other processes of information processing such as stimulus discrimination or evaluation also contribute to the IT task (Vickers & Smith, 1986).

From the present experiments, it is also evident that the effect of subjects' anticipation or attention on their IT task performance should not be neglected, although it is not clear to what extent the process of anticipation may affect one's task performance and how this relationship will change when the warning period is altered (Morrison, 1982). The relationship between the subject's anticipation of the IT task stimulus and his performance on the task might be similar to that between arousal and performance.

Following the approach of information processing, the implication of the above findings is that the inspection time measure might in general index three neural and/or psychological processes, viz. anticipation, the speed of information intake or encoding, and the evaluation of the encoded stimulus. Their relative contributions to the IT measure may vary as a function of, for example, warning period, sensory modality, task requirements, physical characteristics of the stimulus and the like.

Mackenzie & Bingham (1985) have presented three hypotheses of what the IT measure measures and attempted to make a choice between them. These three hypotheses included 'mental speed' (Brand's position), the 'rate of initial information processing' (Nettelbeck's position) and the view that the inspection time measures only a very specific ability to make rapid visuo-spatial discrimination. In my opinion, to make such a choice is, if not impossible, quite difficult, because all these views have something in common, i.e. the speed of information processing. Instead, it may be more fruitful to ask the question: under given conditions, which of these processes (i.e. anticipation, speed of encoding and stimulus evaluation) plays the most important part in relation to the performance of the IT task, and can it be related to intelligence as opposed to the inspection time? The next experiment, which is also the final experiment of this study, will try to answer these questions when the warning period is fixed at 500 msec, the same value as in Exp. 1, 2 and 3.

8.3. The problem of sample size

One of the criticisms of the reported high IT-IQ correlations concerns the population of subjects used in some of the early studies of the IT-IQ investigation, which included mentally retarded people as subjects (Nettelbeck, 1982). In the present experiments, the population of subjects was quite homogeneous. Thus, we do not need to worry about it.

However, in the previous experiments of this study, sample size appears to have made it difficult to find significant correlations between the IT and P200 measures. For instance, the IT-$P200_T$ correlation obtained in Exp. 2 was not low (r=.53 for IT-trial-only whole-epoch analysis, and r=.34 for IT-trial-only window analysis), given that a real association of the two variables is probably somewhere around 0.50 by analogy with the IT-IQ correlation. Because of the small sample (n=8) used, these correlations did not achieve significance. It is possible that this may have merely been a Type II error. For instance, the power coefficient was only 0.37 (one-tailed) under these circumstances (Howell, 1982). It is obvious that a power coefficient of 0.37 was unlikely to result in a significant correlation. To minimize this problem, therefore, it is necessary to take into consideration the power coefficient or the sample size in the next experiment, if we want to draw any conclusion on the IT-P200 relation with confidence.

8.4. Summary

Concerning the relationships between inspection time and AEP components analyzed in the previous experiments of this study, the following results have emerged:

(1) Temporal measures of the P200 component correlated positively with IT scores, and the P200 component was not affected by the factor of task difficulty. In view of the results reported in other ERP studies, these findings were interpreted as suggesting that the P200 component recorded at the vertex may reflect the process of encoding, or transferring, sensory information from iconic storage into STM.

(2) Task difficulty affected the P300 amplitude. The more difficult the trials were, the smaller was the P300 amplitude. The P300 latency correlated positively, but not significantly, with the IT measure. These results were consistent with the hypothesis that the P300 component indicates the completion of the cognitive evaluation of information.

(3) The CNV amplitude was found to correlate positively with the IT measure when the 1800 msec warning period was in use. Since CNV activity indexes subjects' anticipation during a test, this finding implies that the process of anticipation may play an important role in the performance of the IT task.

Based on the above findings and those by other authors, a model for inspection time has been proposed in concrete terms from the point of view of information processing (Salthouse, 1985). The model explains the inspection time measure in terms of three processes, viz. anticipation, the encoding of sensory information and the evaluation of the encoded stimulus.

CHAPTER 9

EXPERIMENT 6: IT-IQ RELATION AND AEP MEASURES

9.1. Introduction

Although the previous experiments have supplied evidence supporting the view that the P200 component indexes the process of encoding, or transferring, information from a sensory register into STM (Chapman *et al.* 1978), there still remain some questions to be answered. For instance, we do not know whether the P200 component of AEPs to stimuli in the IT task reflects a general speed factor underlying all processes requiring an encoding of sensory information, or a speed factor specific to the IT task, and whether these speed factors can be related to intelligence, which is found consistently to correlate negatively with inspection time. Also, we do not know whether a similar correlation between inspection time and the P200 component can be seen in ERPs collected under conditions in which subjects do **not** have to encode sensory information into STM at all. If this is the case, the previous interpretation of what the P200 component indexes will be difficult to sustain. Finally, we do not know whether the same findings can be observed at other position(s) of the scalp, such as the occiput. It is these issues that the present experiment intends to address.

To answer these questions, the present experiment recorded subjects' ERPs from the occiput as well as the vertex. And, it employed three experimental conditions, under which subjects' ERPs were collected. One condition was a number-discrimination task, in which subjects were presented with one of two numbers (or digits) in each trial and asked to make a discrimination. This digit-discrimination task, therefore, served as a general cognitive task. The second condition was equivalent to the IT task, where subjects were presented with their IT-type stimuli and asked to respond to these stimuli in the same way as they did in the previous session of IT estimation (see Section 9.3.2 for detail). The third condition was an IT-task non-loaded condition, in which subjects were also presented with their IT-type stimuli, but not required to make an IT-type discrimination to these stimuli.

In order to avoid a Type II error, the question of sample size should be taken into consideration. Since the IT-$P200_T$ association seen in the previous experiments was somewhere around 0.40 to 0.50, it was decided to use 0.40 as an estimated IT-P200 association in a population. Thus, for a power coefficient of 0.80 (one-tailed) we needed at least 40 subjects in the present experiment (Howell, 1982). In other words, given that the IT-P200 association is about .40 in a population, the probability of disclosing such an association in an experiment with 40 subjects is 8 out of 10.

9.2. Hypotheses and predictions

Hypothesis 1

"The P200 component indexes the general process of encoding sensory information from a sensory register into STM."

Prediction A: Differences will occur between the P200 components of AEPs elicited by IT-type stimuli with and without IT-task requirement or loading, whereas there will be no difference between the P200 components of AEPs elicited by digit stimuli which, by task requirements, subjects have to encode and evaluate.

Prediction B: Temporal measures of the P200 components of AEPs elicited by IT-type stimuli with IT-task loading will correlate positively with inspection time, given that inspection time measures, at least, partially a specific speed factor of the encoding process.

Prediction C: Temporal measures of the P200 components of AEPs elicited by digit stimuli requiring sensory information encoding in general will correlate positively with inspection time, given that inspection time measures, at least partially, a general speed factor of the encoding process.

Prediction D: temporal measures of the P200 component of AEPs elicited by IT-type stimulus without IT-task loading will not correlate with inspection time.

Hypothesis 2

"Inspection time reflects, at least partially, one's intellectual ability measured by intelligence tests."

Prediction E: Negative correlations should be seen between inspection time and intelligence measures.

If the above hypotheses and predictions are satisfied, then the following can be tested:

Hypothesis 3

"A general mental speed factor indexed by inspection time accounts for the IT-IQ correlations (Saccuzzo *et al.* 1986)."

Prediction F: Temporal measures of the P200 component of AEPs elicited by digit stimuli which subjects need to encode into STM in general will *correlate negatively with intelligence measures.*

Hypothesis 4

"A specific mental speed factor reflected through inspection time measure accounts for the IT-IQ correlations (Mackenzie & Bingham, 1985)."

Prediction G: Temporal measures of the P200 component of AEPs elicited by IT-type stimuli <u>with IT-task loading</u> will correlate negatively with intelligence measures.

9.3. Methods

9.3.1. Subjects

Forty second-year Psychology undergraduates (10 male and 30 female) ranging in age from 18 to 21 years (average 19.6) participated in this experiment. They had normal or corrected-to-normal vision.

9.3.2. Experimental design

1) *Estimation of subjects' inspection time* Each subject started the experiment by having his/her IT tested. The accuracy criterion for the IT estimation was 85%. The stimuli used here were the same as in Exp. 3, except that the cue signal was the horizontal bar 18mm long in the middle of the display panel on the front of the LED box (Diagram 9.1). The test took place in the same darkened room as before and all subjects were instructed to indicate at which side the longer vertical line had appeared by pressing the corresponding lever. In contrast to the previous experiments where responses were released after the offset of the mask and without time constraint, in this experiment subjects were asked to withhold their responses for a while after

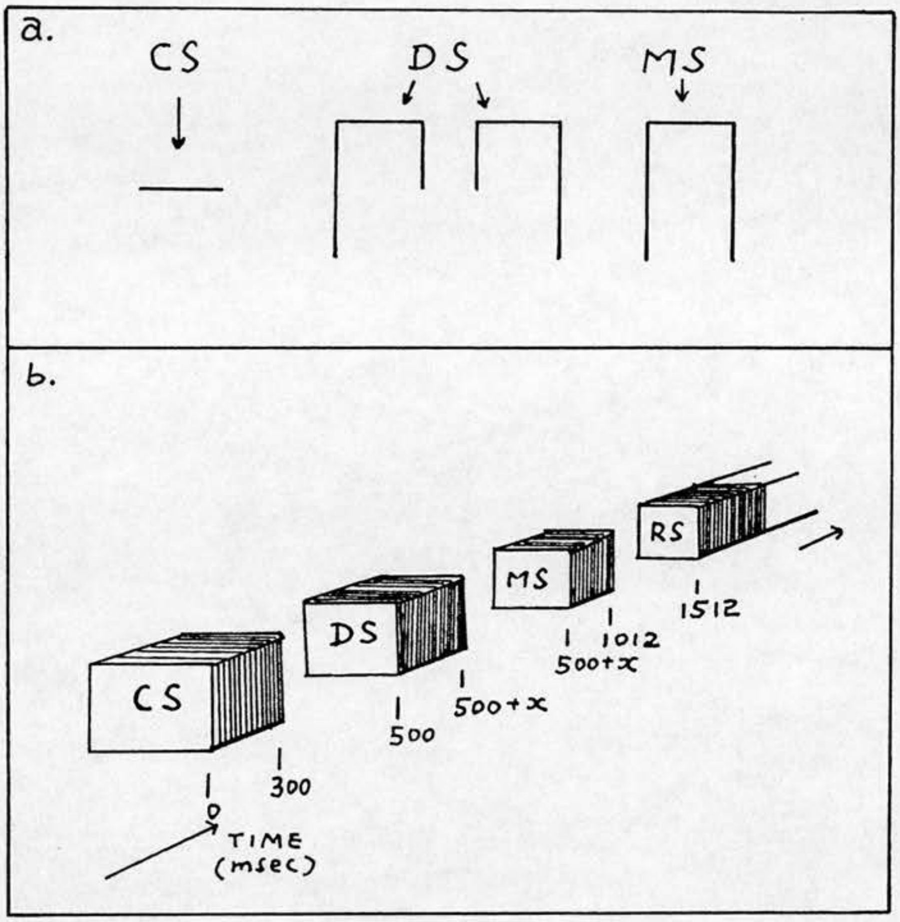

Diagram 9.1

Diagram 9.1a shows the patterns of the cue signal (CS), the discriminative stimulus (DS) and the backward mask (MS). Diagram 9.1b outlines the procedure. RS: response signal (see Diagram 9.2a).

the mask offset and press the appropriate lever as quickly as possible when a rectangular signal 26mm long and 18mm wide (response signal) appeared on display.[1] The response signal always occurred 500 msec after the offset of the mask (Diagram 9.1).

2) *Experimental conditions for ERP collection* Subjects' ERPs were recorded in relation to three experimental conditions, which were: 1) a general encoding and evaluation with digit stimuli (digit discrimination); 2) the specific encoding and evaluation with IT-type stimuli (IT-task loading); and 3) the attention-only condition with the presentation of an IT-type stimulus which served merely as a visual stimulus (IT-task non-loading).

In each trial, the cue signal with a duration of 300 msec was displayed first. 200 msec later, subjects were presented with a digit either 2 or 6, which was exposed for 512 msec (Diagram 9.2). 200 msec after the digit disappeared, subjects' IT-type stimulus (i.e. IT estimate plus the mask) (see Section 2.2.3) was presented, which also lasted for 512 msec. The response signal occurred 500 msec after the offset of the IT-type stimulus. Subjects were told that one of the two digits was task-related and the other task-free. Their task was to discriminate the IT-type stimulus following a digit in the same way as they did in the previous session of IT estimation if the digit was task-related (IT-task loading trial), and do nothing to that stimulus if the digit was task-free (IT-task free, or non-loading, trial). The following is an example of the written instruction to 10 of the 40 subjects:

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[1] The written instruction given to subjects for this session was: 'The task is to look at the test stimulus, wait till the mask dies out, and press, when you see the response signal, the lever corresponding to the side at which the longer line in the previous test stimulus had appeared, as quickly as possible. If you have difficulties in making a judgment, give a guess please.'

> 'If the number is **6**, treat the following stimulus as the test stimulus, and do in the same way as you did in the previous session, i.e. press, when you see the response signal, the lever corresponding to the side at which the longer line in that stimulus had appeared as quickly as possible. When having difficulties, give a guess.
>
> If the number is **2**, your task is merely a simple reaction time task, i.e. press the left lever as quickly as possible when you see the response signal.'

In both situations, subjects were asked to press the appropriate lever as quickly as possible when they saw the response signal. Half subjects were told to press the lever at left side in the task-free trials, and the other half to press the lever at right side. Reaction times were recorded in this session for individual trials. The two digits indicating whether a trial was task-related or task-free were also balanced among subjects. The presentation of digits was randomized and so was the post-response interval, which ranged from 2 to 3 seconds. There were 140 trials in total. Half of them were task-related and the other half task-free.

Requiring subjects to make their responses in the delayed and timed mode served three purposes (Schafer *et al.* 1981). First, ERPs recorded were free of the disturbance caused by finger movement. Second, timing subjects' responses to the response signal ensured that subjects' attention did not occasionally drift away from the task when they encountered the IT-task free trials. An obvious prediction here would be that subjects' simple reaction time under the IT-task free condition (RT-F) should be shorter than, or equal to, the reaction time under the IT-task loading condition (RT-L). Comparing the former with the latter would allow us to see whether subjects had done their job properly or not. Third, both RT-F and RT-L could be compared with other measures taken in the experiment.

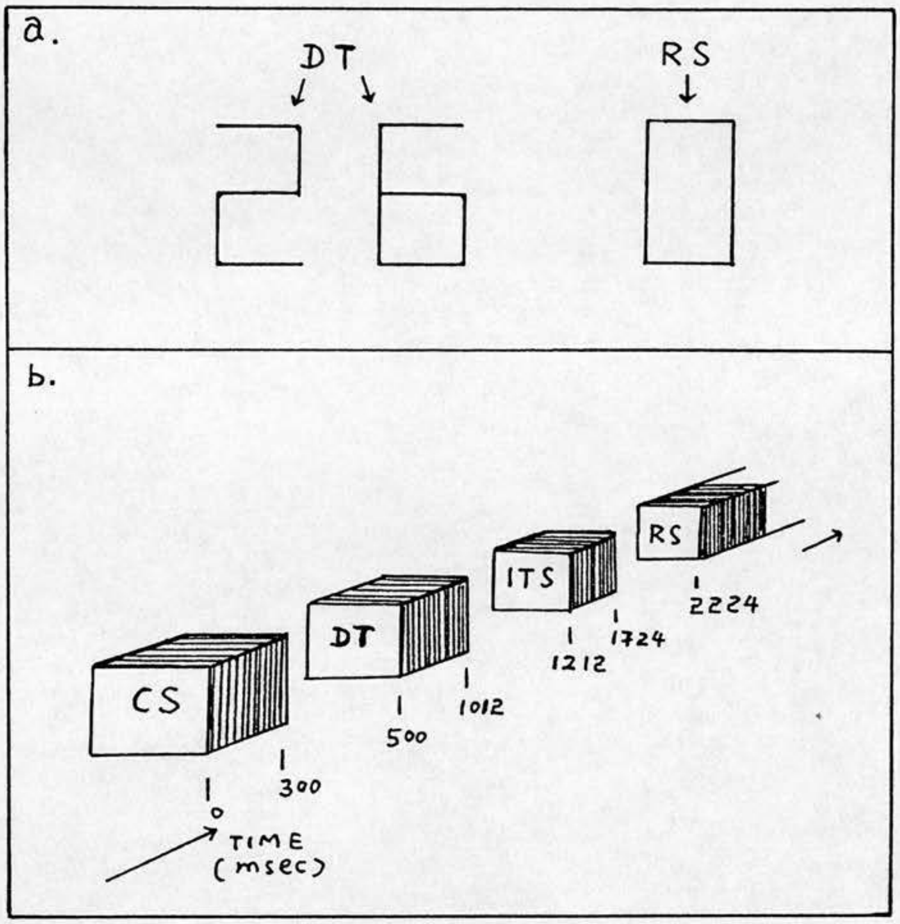

Diagram 9.2

Diagram 9.2a shows the two digit stimuli (2 and 6) (DT) and the pattern of the response signal (RS). Diagram 9.2b outlines the procedure. ITS: IT-type stimulus.

3) *Measurement of intelligence* Subjects' intellectual ability was tested using the AH5 intelligence test, as the AH5 is a test able to discriminate among subjects with high level ability.

9.3.3. ERP data recording

A PA-400 amplifier was used for ERP recording and the recording arrangement remained as before. The ERPs elicited by either digit or IT-type stimuli were collected from the occiput (O_z) as well as the vertex (C_z). The sampling started 50 msec before the onset of each stimulus and lasted 550 msec. The first 50 msec thus served as the CNV measure. Single recordings were kept for off-line analysis.

9.3.4. Procedure

Subjects' IT measures were tested first, and then, after a break of about 10 minutes, the ERP recording session began. There was a warm-up practice before each session. None of these subjects had any difficulty in understanding the tasks. The electrodes were attached to subjects' heads during the break. Resistances were monitored before and after the recording. The mean resistance was 4.65 Kohms and the S.D. 1.82 Kohms.

The AH5 intelligence test took place one month later when subjects attended a practical class of Psychology II in the Department. Out of 40 subjects, 38 had their IQ tested.

9.3.5. Data analyses and measures

There was no subjective editing used before averaging and the ERPs were averaged in accord with both task condition and scalp position. The first 64 recordings of each combination were averaged, and then smoothed using the filter described in Section 2.3.1.

The averaged and smoothed waveforms were then submitted to principal components analysis (PCA) to examine the effects of the experimental conditions on the formation of these AEPs.

Individual parameters of the P200 component and the P300 component of AEPs recorded at the vertex were measured later, and their correlations with the other measures taken in this experiment were calculated. The definitions of the P200 and P300 components were the same as described previously. The amplitude measures in this experiment were measured from the mean potential of the 50 msec pre-stimulus epoch (i.e. baseline-to-peak).

9.4. Results and discussion

9.4.1. Scores of IT, AH5 and RT

Table 9.1 lists the mean scores and standard deviations of subjects' IT, AH5 and RT.

Table 9.1
Means and standard deviations of IT, AH5 and RT

	IT(n=40)	AH5(n=38)			RT(n=40)	
		Part 1	Part 2	Total	Loading	Free
Mean	35.80	16.21	19.97	36.18	341.14	290.33
S.D.	9.18	4.02	4.02	6.57	102.07	79.26

Note: units for timed measures were in msec.

The mean IT of 35.80 msec obtained in the present experiment represents a marked increase in comparison with those obtained previously under similar conditions. For instance, the mean IT was 23.87 msec in Exp. 3. The 11.93

msec difference between the two means was found to be highly significant (t=5.251, df=51, p<.0001 for two-tailed test). Subjects' experience when doing the IT task was also consistent with this observation. Some described later that sometimes they saw the difference between the two lines, but it was hard to remember what they did see by the time the response signal came. The interpretation of this finding was straightforward. Subjects in the present experiment were asked to wait for some time before releasing their responses. During the waiting period a mental decision in STM may have been decaying. Thus, subjects needed to encode more information into STM in order to reinforce the decision so that it could be expressed overtly when asked for later. As a result, their ITs had increased.

Another possibility was that the response signal, which was encoded into STM after the decision was made, may have wiped out the trace of that decision if the decision was not strong enough. In order to keep the trace of their decision after the flooding caused by the response signal, subjects had to encode more information to strengthen the decision. It will be interesting to see in the future which of these explanations is more acceptable in a paradigm using an auditory stimulus to deliver the response signal as well as a visual stimulus.

Mean RTs were calculated for each subject and the calculation excluded those single trial RTs which were outside the range of 10 msec to 1000 msec. As predicted, the mean RT (290.33 msec) for the IT-task free trials was shorter than that for the IT-task loading trials (341.14 msec). The 58.81 msec RT difference was highly significant (Wilcoxon: W=56.5, n=40, p<.0001 for one-tailed test). Thus, it can be said with every confidence that these subjects followed the experimental instructions, attended and reacted properly. For instance, only 9 subjects made errors in the IT-task free trials by pressing the wrong lever. The average number of errors made among the 9 subjects was 2.3. The maximum number of errors for any subject was 7, and even so the performance was still significantly higher than chance level (goodness of fit: $\chi^2=43.214$, df=1, $p<.0001$). For the IT-task loading trials, the number of errors made by subjects ranged from 2 to 12, with the average being 5.2. Considering the 85% accuracy criterion used in IT estimation, the average error of 5.2 was not statistically different from the expected error number of 10.5 (goodness of fit: $\chi^2=2.582$, df=1, $p>.20$).

9.4.2. Average evoked potentials across subjects

Unfortunately, before the ERP analysis was carried out three subjects' raw ERP data were corrupted due to a fault in the University computer system (Filestore) where all raw ERPs were kept. Thus, the ERP analyses in the following sections were based on the data from the remaining 37 subjects.

Fig. 9.1 shows the cross-subject averages of these ERPs to the IT-type stimuli and recorded at the vertex. Several differences emerged between conditions with and without IT-task loading. First, the CNV activity was more negative, as was expected, for the IT-task loading trials than for the IT-task free trials, indicating that subjects had quickly developed their anticipation for the following task stimulus after they saw the digit which indicated an IT-task loading trial. The t-test values plotted in the bottom part of the figure illustrate the area in which the differences of the CNV measures under the two conditions were significant. The area seems to have covered the whole pre-stimulus sampling duration and extended to the point of about 75 msec after the stimulus. There was no difference in the range in which the N150 component occurred.

Average evoked potentials elicited by IT−type stimuli and recorded at the vertex

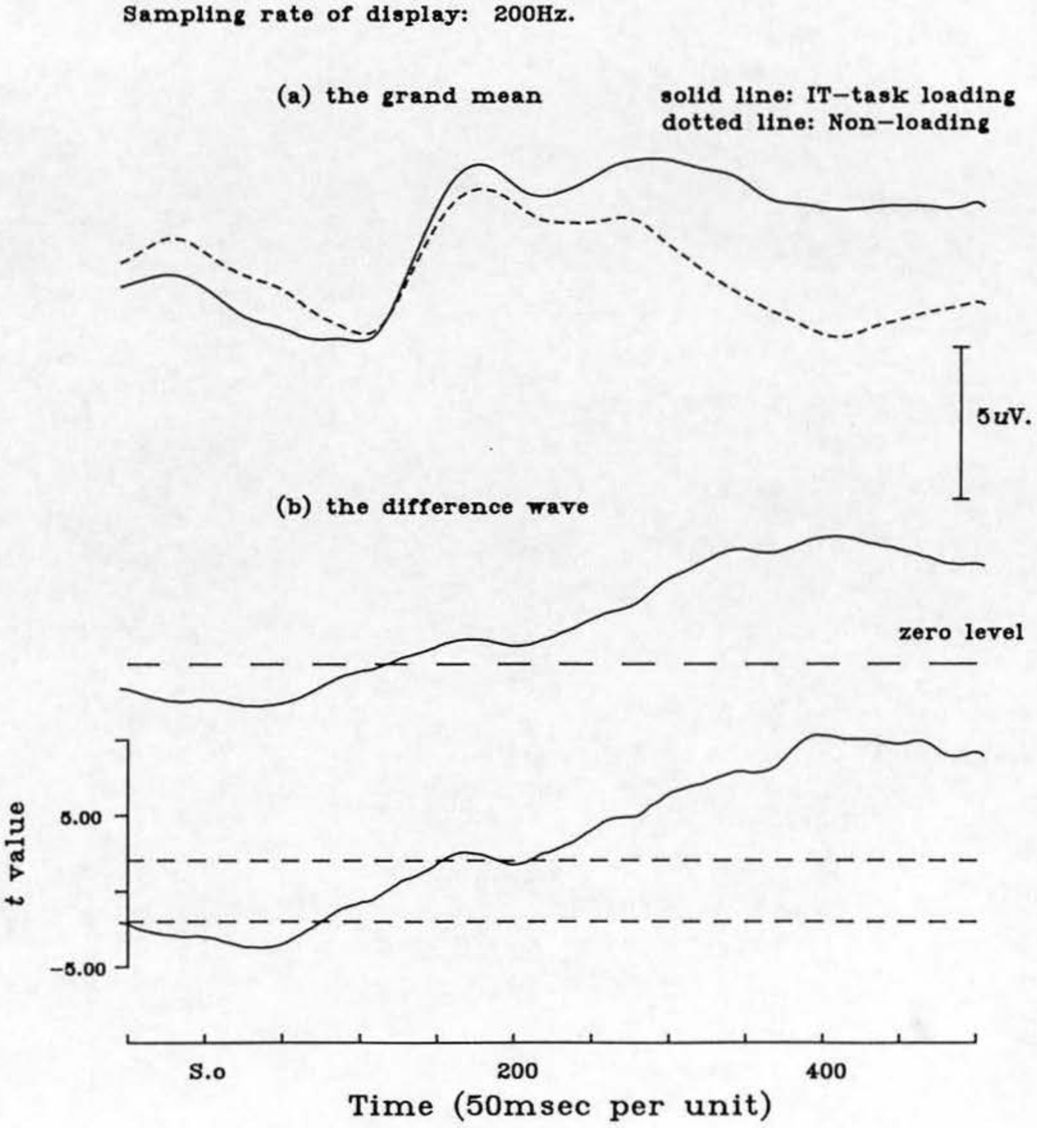

Fig. 9.1 (a) the average evoked potentials from 37 subjects' data, Positivity upwards; (b) the difference between the two averages in (a), and the values of related t tests; the dashed lines indicate the level of .05 significance for two−tailed test.

Second, the P200 components peaking at about 180 msec were significantly different from each other under the two conditions. The P200 amplitude was enhanced in the IT-task loading trials, indicating that more sensory information had been encoded into STM so that a discrimination could be made. It may be argued that the strong CNV activity under the IT-task loading condition could have been responsible for the enhancement of the P200 amplitude. This issue will be discussed later.

Third, the P300 amplitudes were also different under the two conditions. The two traces began to separate dramatically from each other at about 225 msec after the onset of the stimulus, and the separation seems to have increased continuously till about 400 msec. Since subjects were requested to prepare for the coming of the following response signal as soon as they had completed their IT-task discrimination, this finding indicates that the P300 component was indeed reflecting a necessary process which couldn't be separated from the sequence of information processing that had been involved in visual discrimination tasks (McCarthy & Donchin, 1981).

In contrast, cross-subject averages of evoked potentials to the digits, also recorded at the vertex, did not show any differences until the P300 component had occurred (Fig. 9.2). After the occurrence of the P300 component the two traces sailed apart distinctively. The trace to the task-related digit sloped down quickly as the subjects prepared for the impending IT-type stimulus to which they had to make a discrimination. Thus, according to the above results *prediction A* was confirmed.

AEPs recorded at the occiput (Fig. 9.3 and Fig. 9.4) drew a slightly different picture. The P200 components of AEPs elicited by the IT-type stimuli did not show any differences between the conditions with and without IT-task loading

Average evoked potentials
elicited by digit stimuli
and recorded at the vertex

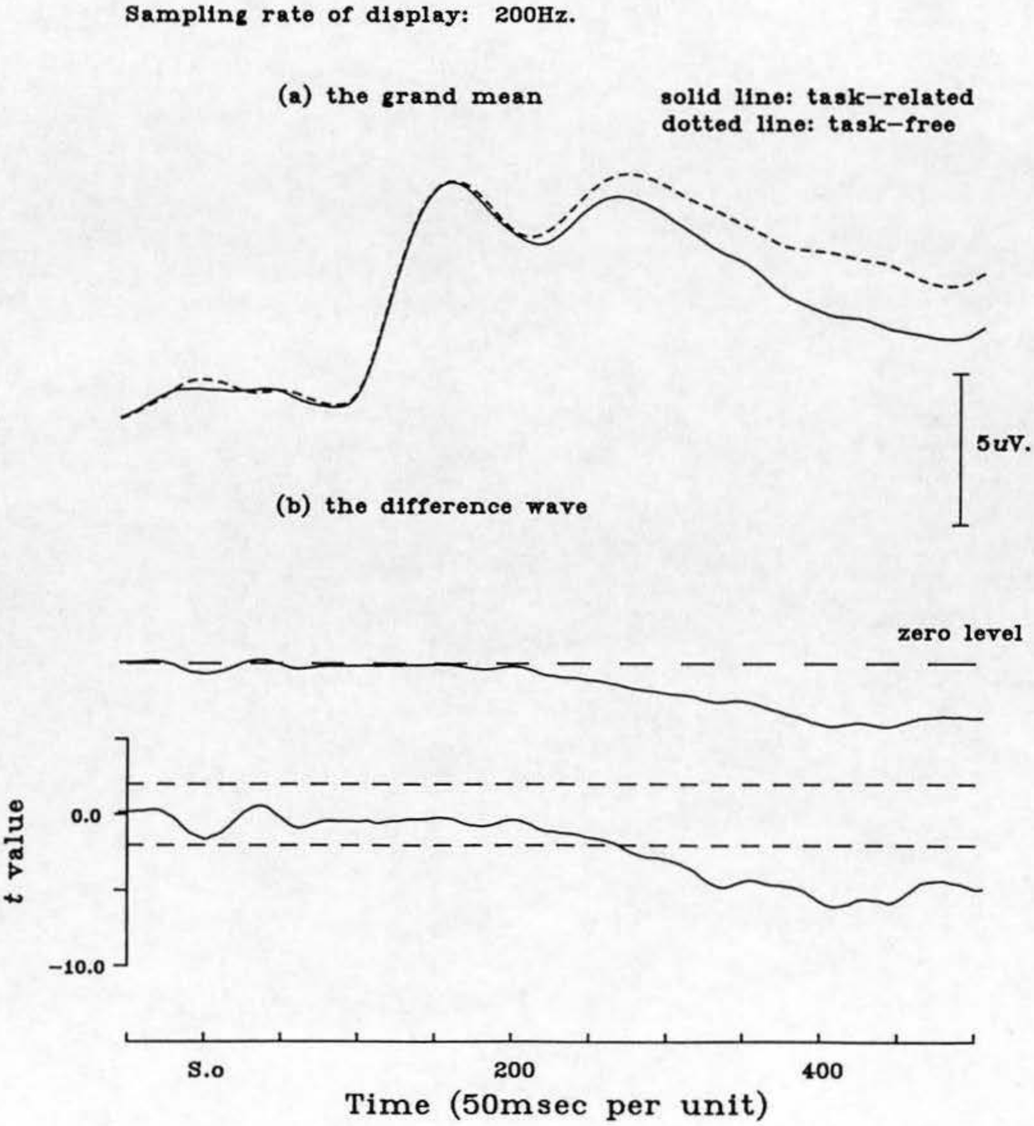

Fig. 9.2 (a) the average evoked potentials from 37 subjects' data, Positivity upwards; (b) the difference between the two averages in (a), and the values of related t tests; the dashed lines indicate the level of .05 significance for two–tailed test.

Average evoked potentials elicited by IT–type stimuli and recorded at the occiput

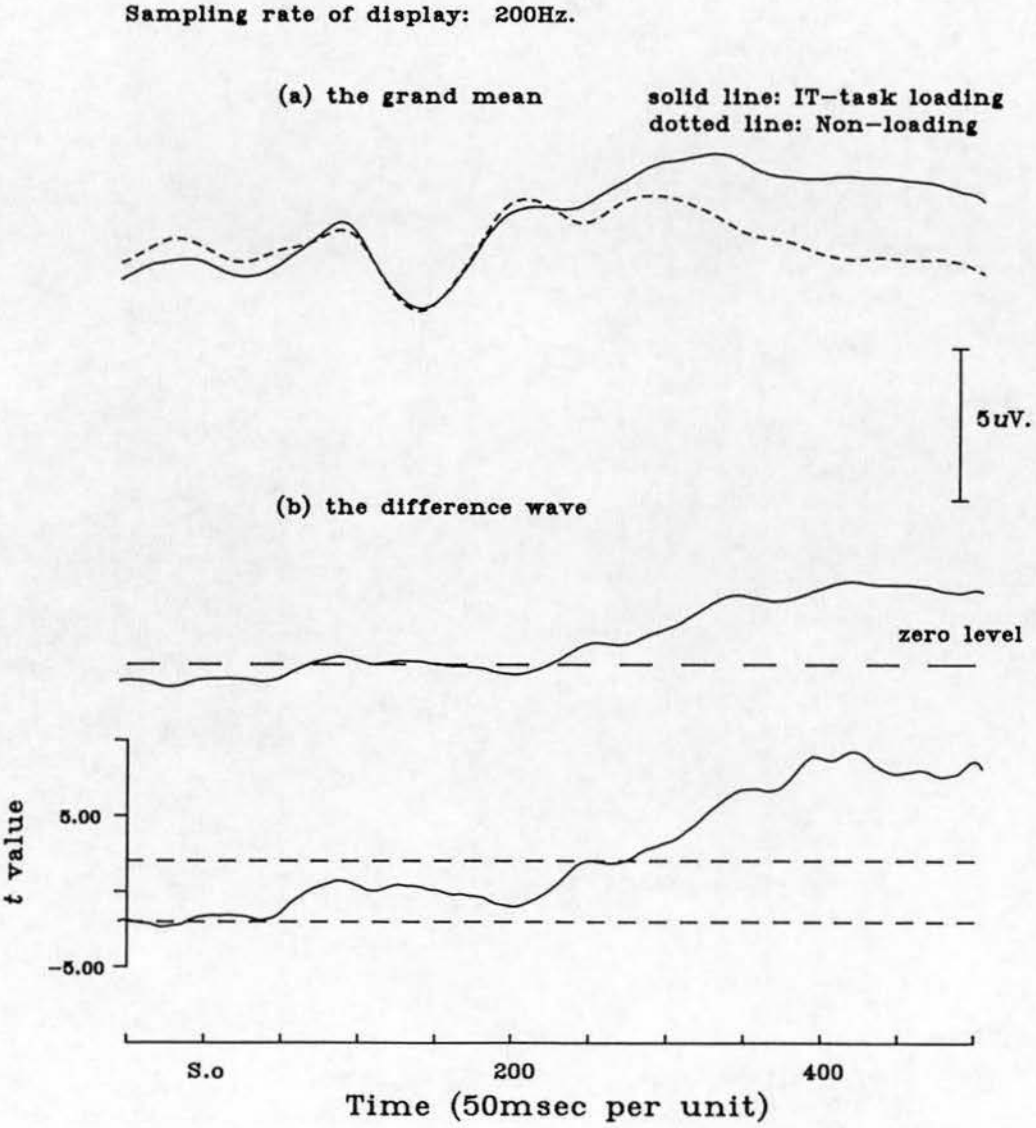

Fig. 9.3 (a) the average evoked potentials from 37 subjects' data, Positivity upwards; (b) the difference between the two averages in (a), and the values of related t tests; the dashed lines indicate the level of .05 significance for two–tailed test.

Average evoked potentials elicited by digit stimuli and recorded at the occiput

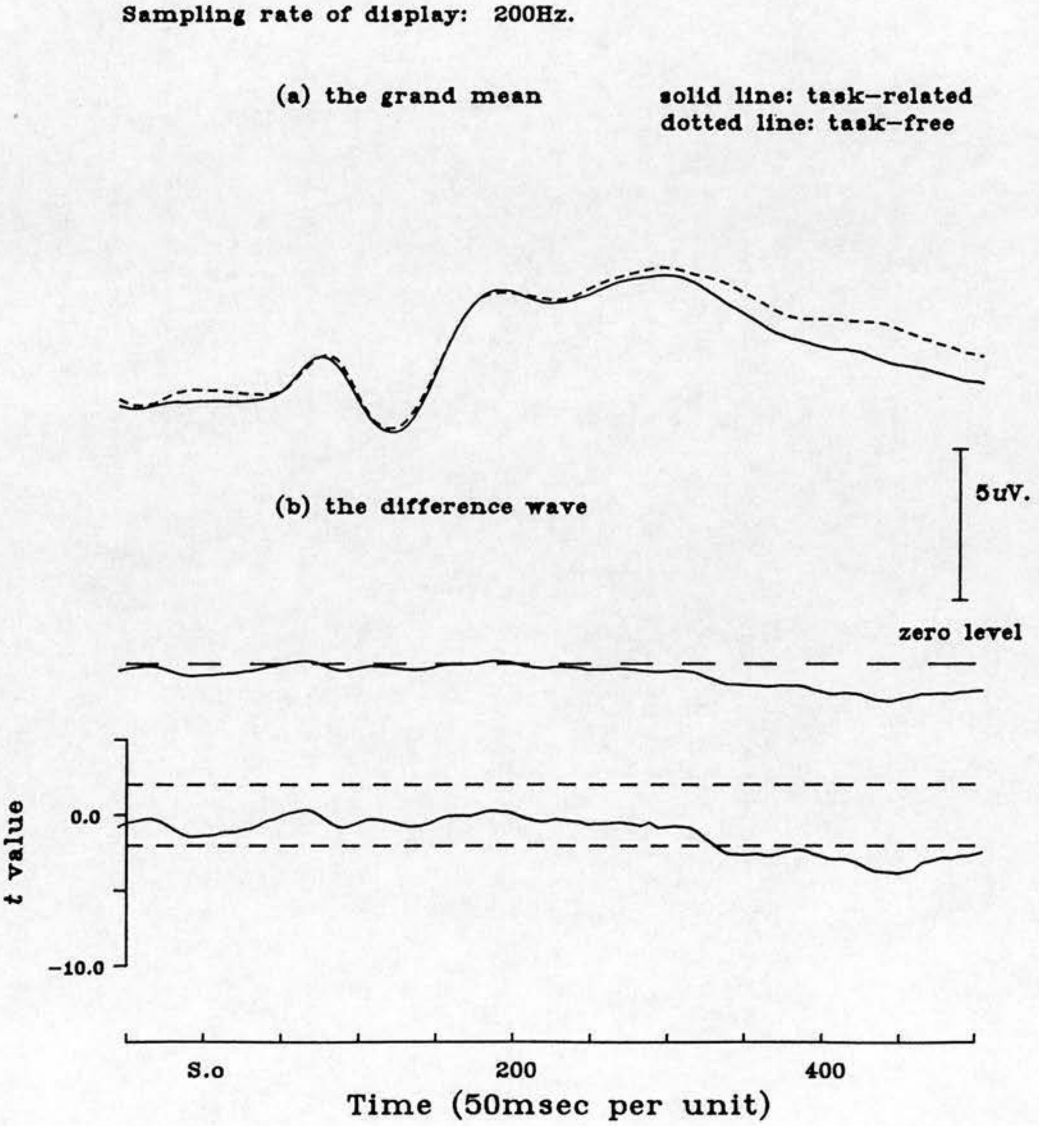

Fig. 9.4 (a) the average evoked potentials from 37 subjects' data, Positivity upwards; (b) the difference between the two averages in (a), and the values of related t tests; the dashed lines indicate the level of .05 significance for two-tailed test.

(Fig. 9.3). However, this result should not be considered contradictory to the above discussion about the P200 component because the vertex potential may well have reflected a relatively high level of information processing. Rather, it implies that the P200 component at the vertex is at least partially endogenous. The CNV component recorded at the occiput did manifest the difference between conditions with and without IT-task loading. But, the difference was very small in comparison with what was seen at the vertex.

9.4.3. Results from principal components analysis

Principal components analysis (PCA) was applied to the AEPs to the digit stimuli and to the IT-type stimuli, respectively. The data base for each PCA was 148 cases by 50 time points (2 task conditions x 2 scalp positions x 37 subjects). The AEP epoch which was analysed was 500 msec in length, starting from the onset of the stimulus. The eigenvalue was defined at 3.0 (see Section 2.3.7 for explanation), and the covariance matrix with varimax rotation was used for extracting factors (BMDP4M, Dixon, 1983).

Four factors resulted from each analysis and they are shown in Fig. 9.5. Factor 1, 3 and 4 in the IT-type stimulus condition were almost identical to their counterparts in the digit stimulus condition. For factor 2, however, there was a clear difference of configuration between the two stimulus conditions. The left-side slope of factor 2 under the IT-type stimulus condition was smoother than that under the digit stimulus condition. In the latter case, a peak occurred half way up the left-side slope of factor 2 (Fig. 9.5).

Regarding the peaking latency of these factors, factor 1 appeared to correspond to the epoch of AEPs from 300 msec onwards after the stimulus (also see the previous figures). Factor 2 covered the range in which the P200 and P300 components had occurred. Therefore, this factor may have been an

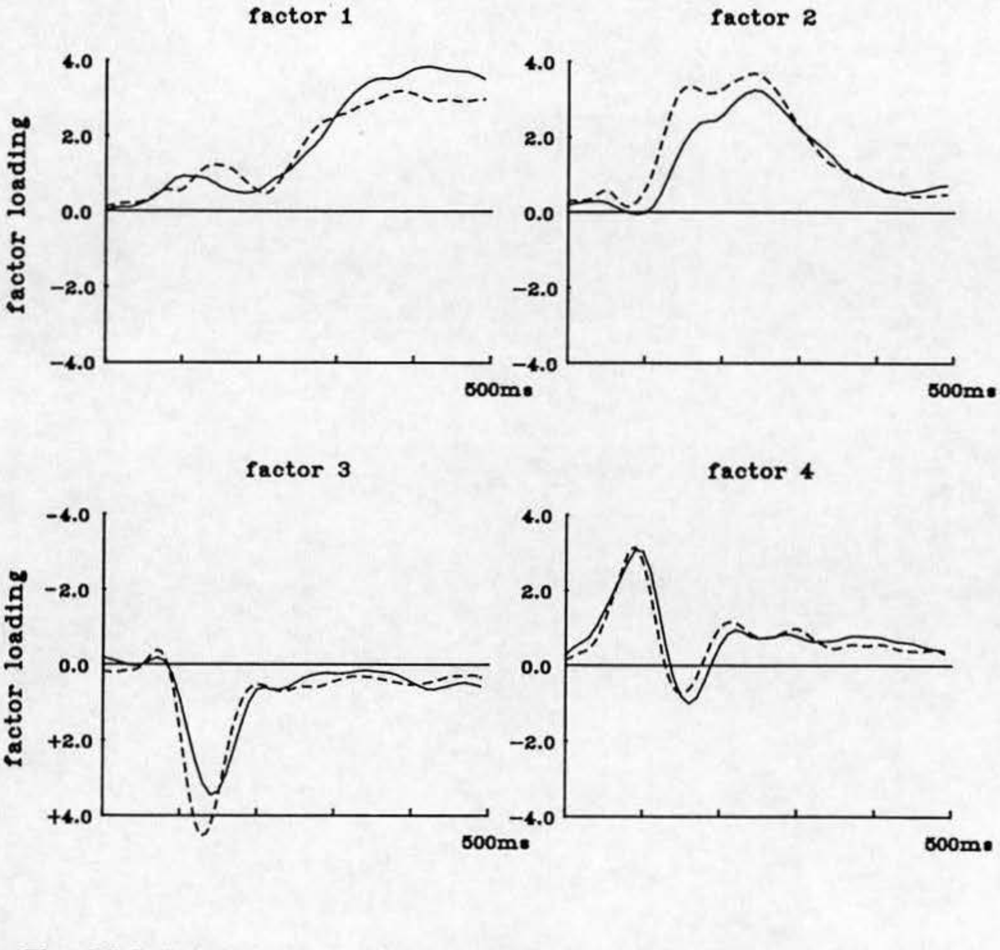

Fig. 9.5 Rotated factor loadings plotted according to shape and latency. Factors in the solid line came from the evoked potentials to the IT–type stimuli, and factors in the dotted line from the evoked potentials to the digit stimuli.

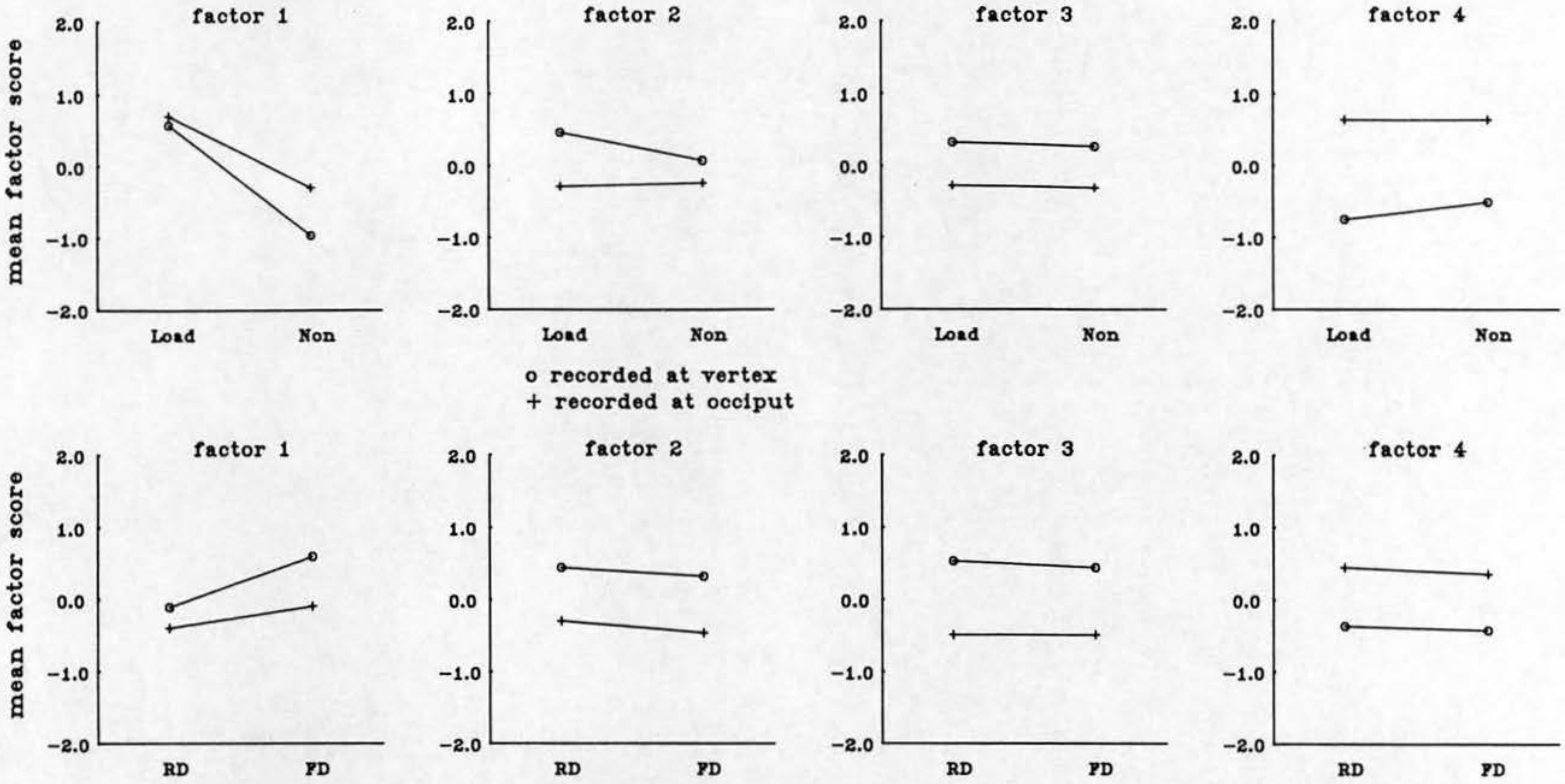

Fig. 9.6 Factor scores plotted as a function of conditions and positions. Top row: the IT-type stimulus condition; Bottom row: the digit stimulus condition. Load: IT-task loading trial; Non: Non-loading trial; RD: task-related digit; FD: task-free digit.

amalgam of the two components. Factor 3 was obviously equivalent to the N150 component, and factor 4 equivalent to the P100 component. The P100 component can be clearly seen in the AEPs recorded at the occiput (see Fig. 9.3 and Fig. 9.4).

Fig. 9.6 depicts the mean factor scores of the cases in each PCA, and Table 9.2 lists the resultant statistics. On the one hand, there existed a strong effect of scalp position on AEPs. The AEPs recorded at the vertex scored more on factor 2 and factor 3 than those recorded at the occipital area (Picton *et al.* 1974). Factor 4 appeared to be more strongly represented in the latter location. Scores of AEPs on factor 1 varied as a function of the cognitive nature of the IT-type stimuli. However, the effect of recording location was of little interest to the concerns of the present experiment.

The effects of task conditions on AEPs were only seen in factor 1. Under the IT-type stimulus condition AEPs scored more on this factor for the IT-task loading trials than for the IT-task free trials (F(1,36)=124.7, p<.001). Under the digit stimulus condition AEPs scored less for the task-related trials than for the task-free trials (F(1,36)=24.93, p<.001). All these findings were consistent with the results described previously.

There was, however, an interesting finding revealed by the PCA: the interaction effect of task and position on AEPs for factor 2. This effect was seen under the IT-type stimulus condition (F(1,36)=17.41, p<.001), but not under the digit stimulus condition (F(1,36)=0.21, n.s.), thus indicating that the AEPs' epoch from about 150 msec to about 300 msec was indeed differentiated by the conditions with and without IT-task loading, although the size of the effect depended upon the scalp position.

Table 9.2 A two-way ANOVA on factor scores

St.	Factors	Sources	SOS	df	MS	F	P
IT-type	1	Load vs Non	59.870	1	59.870	124.74	.001
		Error	17.279	36	0.480		
		Ver vs Occi	5.849	1	5.849	17.01	.001
		Error	12.377	36	0.344		
		Interaction	2.800	1	2.800	14.09	.001
		Error	7.152	36	0.199		
	2	Load vs Non	1.056	1	1.056	1.98	n.s.
		Error	19.183	36	0.533		
		Ver vs Occi	10.595	1	10.595	15.81	.001
		Error	24.127	36	0.670		
		Interaction	1.796	1	1.796	17.41	.001
		Error	3.713	36	0.103		
	3	Load vs Non	0.115	1	0.115	0.41	n.s.
		Error	10.180	36	0.283		
		Ver vs Occi	12.490	1	12.490	8.12	.01
		Error	55.373	36	1.538		
		Interaction	0.004	1	0.004	0.06	n.s.
		Error	2.283	36	0.063		
	4	Load vs Non	0.536	1	0.536	1.74	n.s.
		Error	11.080	36	0.308		
		Ver vs Occi	58.443	1	58.443	79.66	.001
		Error	26.411	36	0.734		
		Interaction	0.572	1	0.572	12.85	.002
		Error	1.602	36	0.045		
Digit	1	Rel vs Free	9.632	1	9.632	24.93	.001
		Error	13.911	36	0.386		
		Ver vs Occi	8.777	1	8.777	12.02	.002
		Error	26.285	36	0.730		
		Interaction	1.536	1	1.536	14.21	.001
		Error	3.892	36	0.108		
	2	Rel vs Free	0.689	1	0.689	2.54	n.s.
		Error	9.755	36	0.271		
		Ver vs Occi	21.594	1	21.594	23.61	.001
		Error	32.922	36	0.915		
		Interaction	0.014	1	0.014	0.21	n.s.
		Error	2.353	36	0.065		
	3	Rel vs Free	0.120	1	0.120	0.85	n.s.
		Error	5.037	36	0.140		
		Ver vs Occi	33.690	1	33.690	36.05	.001
		Error	33.647	36	0.935		
		Interaction	0.103	1	0.103	4.07	n.s.
		Error	0.912	36	0.025		
	4	Rel vs Free	0.198	1	0.198	1.38	n.s.
		Error	5.159	36	0.143		
		Ver vs Occi	23.402	1	23.402	16.11	.001
		Error	52.287	36	1.452		
		Interaction	0.010	1	0.010	0.19	n.s.
		Error	1.943	36	0.054		

Note: Load stands for IT-task loading; Non for Non-loading;

Rel for task-related digit; and Free for task-free digit.
Ver vs Occi represents vertex vs occiput.

In a further analysis, it was found that the scores on factor 2 were affected significantly by the conditions with and without IT-task loading for the vertex ($t=2.52$, $df=36$, $p<.02$ for two-tailed test), but not for the occiput ($t=0.96$, $df=36$, n.s.).

However, it was hardly possible to tell which component might have been responsible for this effect since factor 2 occurred within the latency range of 150 msec to 300 msec and must have contained contributions from both the P200 and P300 components.

There was also an interaction effect on AEPs for factor 4 under the IT-type stimulus condition ($F(1,36)=12.02$, $p<.002$). It can be seen from Fig. 9.6 that AEPs recorded at the vertex scored less on this factor for the IT-task loading condition than for the non-loading condition ($t=2.38$, $df=36$, $p<.05$ for two-tailed test), and no such difference was found between these two conditions for AEPs recorded at the occiput ($t=0.04$, $df=36$, n.s.). It was believed that the strong CNV activity observed at the vertex (Fig. 9.1) might have flattened the P100 component in the IT-task loading trials, and caused this effect.

9.4.4. Individual parameters of AEP components

For the AEPs recorded at the vertex, parameters of both the P200 component and the P300 component were measured by latency and amplitude. The 50 msec pre-stimulus recording served as the baseline for the amplitude measures. As in Exp. 3, the $P200_T$ measure was taken from the 75-275 msec window analysis. Table 9.3 contains the means and standard deviations of these measures and the results of relevant statistical tests.

Table 9.3
Means, standard deviations and relevant statistics

(n=37)		IT-type stimulus				
Parameters	Loading		Non-loading		T-test	P(1-tail)
	Mean	S.D.	Mean	S.D.		
CNV	17.66	2.17	16.76	1.71	2.53	<.01
$P200_L$	183.09	25.04	177.59	20.05	1.34	n.s.
$P200_A$	4.89	2.49	2.89	2.59	5.31	<.001
$P200_T$	39.12	19.96	37.11	17.01	0.57	n.s.
$P300_L$	306.53	36.00	293.95	36.74	1.93	<.05
$P300_A$	5.39	3.08	1.38	3.40	6.28	<.001

(n=37)		Digit stimulus				
Parameters	Related		Free		T-test	P(1-tail)
	Mean	S.D.	Mean	S.D.		
CNV	17.66	1.95	17.64	1.99	0.06	n.s.
$P200_L$	166.84	19.32	165.45	19.79	0.50	n.s.
$P200_A$	8.14	2.86	8.12	2.80	0.11	n.s.
$P200_T$	32.68	14.83	28.65	12.68	1.87	n.s.
$P300_L$	288.51	37.88	289.74	36.68	0.26	n.s.
$P300_A$	7.34	3.22	8.61	3.21	3.84	<.001

note: units were msec for time measures, and μV for amplitude measures; larger values of CNV measure represent more negativity.

For the digit stimulus, on the one hand, the data showed no significant differences between the measures of the P200 component for task related and free conditions (t=0.5 for the $P200_L$, t=0.11 for the $P200_A$, and t=1.87 for the $P200_T$). This was consistent with *prediction A*, which states that there will be no differences between the P200 components of AEPs to stimuli which ask for encoding and evaluating. On the other hand, the task conditions (related vs free) did not affect the P300 latency (t=0.26); the P300 amplitude was smaller in the task-related trials than that in the task-free trials (t=3.84, df=36, $p<.001$ for one-tailed test). This significant difference in amplitude of the P300 component suggested that although the P300 latency was contingent on the completion of a mental decision (McCarthy & Donchin, 1981), the P300 amplitude may have reflected at least partially the content of that mental decision (Sutton *et al.* 1965). In other words, a mental decision is not made suddenly after the evaluation of stimulus. Rather, it occurs gradually when the evaluation is going on (see Fig. 9.2).

For the IT-type stimulus, as expected, the CNV was more negative before the onset of the stimulus in the IT-task loading trials than in the IT-task non-loading trials ($t=2.53$, $df=36$, $p<.01$ for one-tailed test), indicating that subjects paid closer attention to the IT-type stimulus in the IT-task loading trials. For the P300, it was found that its amplitude was much larger for the IT-task loading condition (5.39 *μV*) than for the IT-task non-loading condition (1.38 *μV*) ($t=6.28$, $df=36$, $p<.001$ for one-tailed test), and that its latency was longer in the IT-task loading trials (306.51 msec) than in the IT-task non-loading trials (293.95 msec) ($t=1.93$, $df=36$, $p<.05$ for one-tailed test). These results were consistent with McCarthy and Donchin's view (1981) and the other findings about the P300 component in the literature (Pritchard, 1981).

It was predicted (*prediction A*) that differences between the measures of the P200 component of AEPs to the IT-type stimuli would emerge under the two conditions with and without IT-task loading. As can be seen, the P200 amplitude under the loading condition was almost twice as big as that under the non-loading condition ($t=5.31$, $df=36$, $p<.001$ for one-tailed test). However, it still remains to be discussed whether this finding confirmed *prediction A* or merely reflected the effect of the preceding differential CNV activity on the P200 component.

9.4.5. Correlations between measures concerned

Correlation coefficients were calculated using Corr Pearson in SPSS-X.

1) *Correlations between IT, AH5 and RT measures* Table 9.4 lists the correlations between IT, AH5 and RT measures. The correlation between the IT measure and the total score of AH5 was significantly negative (*prediction E*) (r=-.301, n=38, p<.05, one-tailed), which was consistent with the results of other authors (Brand & Deary, 1982; Anderson, 1986; Nettelbeck *et al.* 1986a). This finding, thus, suggests that the IT-IQ relation can be seen even in a student population, and that subjects with high intelligence measured by IQ tests can do better on the IT task than do subjects who are slightly less intelligent (though still within the high-IQ range).

Table 9.4
Correlations between IT, AH5 and RT

Measures	IT	AH5			RT
		Part 1	Part 2	Total	Loading
AH5 Part 1	-.214				
Part 2	-.293*	.334**			
Total	-.301*	.817	.817		
RT Loading	.189	.098	.229	.200	
Free	.112	.129	.148	.169	.767***

Note: * p<.05; ** p<.025; *** p<.0005, 1-tailed.

The correlations between IT and RT measures were not significant (Vernon, 1981, 1986; Salthouse, 1985). This seems to agree with Vernon's (1986) suggestion that the IT and RT measures may reflect different mental processes. No significant correlations were found between AH5 and RT measures.

2) *Correlations of the CNV measure with IT, AH5 and RT scores* As the

measure of the CNV amplitude under the IT-type stimuli was larger (i.e. more negative) for the loading condition than for the non-loading condition, a difference measure was also taken by subtracting the CNV of the latter from that of the former. For the digit stimuli, because there was no difference seen previously in the CNV measures (Fig. 9.2 and Table 9.3), the average of the two CNV measures corresponding to the two conditions was also calculated. Table 9.5 contains the correlations of the resultant CNV measures with the IT, AH5 and RT scores.

Table 9.5
Correlations of the CNV amplitude with IT, AH5 and RT

		(n=37)	(n=37)			(n=35)	
Stimuli	CNV	IT	RT			AH5	
			Load	Free	Part 1	Part 2	Total
IT-type	Loading	.231	.169	.203	.006	-.036	-.017
	Non	.168	-.165	-.029	-.085	.033	-.032
	Diff	.097	-.257	-.118	.073	-.062	.007
Digit	Related	.013	.042	-.016	-.162	-.111	-.158
	Free	-.057	.161	.035	-.017	-.100	-.077
	Mean	-.024	.110	.011	-.095	-.113	-.126

Unlike in Exp. 4 and 5, the warning period used in the present experiment was 500 msec, which was the same as used in Exp. 1, 2 and 3. No CNV measures correlated with inspection time. These results suggest that when the warning period was short the individual differences in the speed of the development of anticipation and in the maintenance of anticipation may have had little contribution to the outcome of subjects' performance on tasks like the inspection time (Morrison, 1982). Neither AH5 nor RT scores correlated significantly with these CNV measures.

3) *Correlations of the P200 measures with IT, AH5 and RT scores*

Correlations of the measures of the P200 component with IT, AH5 and RT scores are given in Table 9.6. Because the P200 components were not different from each other for the digit stimulus condition (Table 9.3), the correlations were calculated based on the averages of corresponding parameters under the two digit conditions.

Table 9.6
Correlations of the P200 measures with IT, AH5 and RT

		(n=37)	(n=35)			(n=37)	
Cond.	Measures	IT	AH5			RT	
			Part 1	Part 2	Total	Load	Free
(IT-type)							
Loading	$P200_L$	$.442^{**}$	.139	.028	-.017	$.370^{*}$	$.379^{*}$
	$P200_A$	$.332^{*}$	.229	-.047	.101	-.140	-.096
	$P200_T$	$.645^{***}$	.156	.001	.111	$.373^{*}$	$.416^{*}$
Non	$P200_L$	.070	.145	.121	.160	.208	.243
	$P200_A$	.253	-.005	-.153	-.095	.017	-.019
	$P200_T$	.117	.004	.074	.047	.210	.206
(Digit)							
Mean	$P200_L$	-.003	-.114	.112	.119	.044	.009
	$P200_A$	-.000	.152	.171	.195	.017	-.004
	$P200_T$	$.290^{*}$	$-.422^{**}$	-.137	$-.339^{*}$	.004	-.014

Note: * $p<.05$; ** $p<.005$; *** $p<.0005$, 1-tailed.

Highly significant correlations of the temporal measures of the P200 component with inspection time under the IT-task loading condition were obtained once again (Table 9.6), which confirmed *prediction B*.

The correlation between the $P200_T$ of the digit condition and the IT measure provided the evidence supporting *prediction C* ($r=.290$, $N=37$, $p<.05$, one-tailed).

Prediction F was also confirmed: the $P200_T$ measure of AEPs to the digit stimuli correlated significantly with the AH5 scores ($r=-.339$, $N=35$, $p<.05$, one-tailed).

There was no evidence in favour of *prediction G*, and *prediction D* was not disconfirmed.

Thus, Hypotheses 1, 2 and 3 were supported in this experiment, but not Hypothesis 4 (see Section 9.2).

It may be important to point out here that these correlations were found among a sample of subjects that was quite homogeneous with respect to their intellectual ability. More impressive correlations should therefore be expected of samples of a general population.

It was found, however, that the P200 amplitude also correlated with inspection time ($r=.332$, $n=37$, $P<.05$ one-tailed). Assuming that the P200 amplitude reflected the amount of information which had been encoded into STM (Chapman *et al.* 1978), this finding seems to suggest that subjects with long ITs may have taken into STM more information before a discrimination was to be completed (Davis, 1964), which implied that some differences in characteristics of subjects' evaluation process might have been at least partially accountable for their estimated long ITs.

For instance, subjects with long ITs may have adopted a high criterion of confidence, or response threshold, in their decision making (Vickers & Smith, 1986). They would be unlikely to stop encoding information into STM unless they were perfectly sure that they had got the answer correct (Squires, K.C. *et al.* 1975). When encountering those trials in which the exposure duration of the discriminative stimulus was short, these subjects may not have been able to alter the process of reaching a decision; that is, they must have continued taking further observations, even if this meant encoding from the backward mask (Vickers & Smith, 1986). However, encoding from the non-informational mask stimulus would not help them reach their high response threshold or satisfy their stringent criterion of confidence for decision making. Conversely, it could have contaminated the previously accumulated informative sensory input. Therefore, they had to give a guess response. As a result, they showed a large P200 amplitude as well as a long IT.

To find out evidence for this interpretation, the correlations between the IT measure and P300 amplitude were examined and presented in next section. As the P300 amplitude reflects the level of subjects' confidence in their task performance (Hillyard, 1971; Kutas *et al.* 1977; Ruchkin *et al.* 1980b), we would expect that a longer IT estimate would be associated with a larger amplitude of the P300 component to the IT-type stimulus in the IT-task loading trials, if the above interpretation was acceptable.

4) *Correlations of the P300 measures with IT, AH5 and RT scores* Table 9.7 lists the correlations of the measures of the P300 component with IT, AH5 and RT scores. It was found that the P300 amplitude of AEPs to the IT-type stimuli in the IT-task loading trials correlated positively with inspection time (r=.503, n=37, p<.01, two-tailed). As discussed previously, the P300 amplitude reflects subjects' confidence in their task performance, and varies as a function of task difficulty (see Exp. 1 and 2) and behavioural outcome (see Exp. 3 and 4). This finding was in support of the interpretation that subjects with long ITs may have adopted a high confidence criterion, or response threshold, when making their discriminations and decisions (Vickers & Smith, 1986). For instance, it was reported that subjects' confidence rating was increased with the number of line segments presented (equivalent to the duration of the stimulus presentation) (p<.001), and was greater in correct responses than in incorrect

response (p<.001) (Vickers *et al.* 1985).

Table 9.7
Correlations of the P300 measures with IT, AH5 and RT

		(n=37)		(n=35)		(n=37)	
Cond.	Measures	IT	AH5			RT	
			Part 1	Part 2	Total	Load	Free
(IT-type)							
Loading	$P300_L$	.055	-.026	.135	.066	-.112	-.121
	$P300_A$	.503*	.167	.118	.173	.048	-.026
Non	$P300_L$	.061	-.251	.150	-.062	.179	.148
	$P300_A$	.068	.055	.059	.069	.257	.178
(Digit)							
Related	$P300_L$	.203	-.197	.074	-.075	-.149	-.158
	$P300_A$	-.020	.205	.184	.221	.060	.071
Free	$P300_L$	.013	-.084	.057	-.017	.015	.053
	$P300_A$	-.014	.033	.161	.129	.117	-.066

Note: * p<.01, two-tailed.

9.4.6. The PCA for some relevant variables

Based on the results presented above, it seemed worth performing a principal components analysis (PCA) on those measures which had been most illuminating in the investigation of the relationships between AEPs, IT and IQ, in order to find out the main factors which underlie the relations found among them.

Eight measures were used for this purpose, which included IT, AH5-I, AH5-II, four AEP measures from the IT-type stimulus condition ($P200_L$, $P200_A$, $P200_T$, and $P300_A$), and one AEP measure from the digit stimulus condition ($P200_T$).

Table 9.8 shows the correlation matrix of the eight selected measures. Three factors were revealed using the PCA with varimax rotation (BMDP4M, Dixon, 1983). Table 9.9 lists the factor loadings of each of the eight measures on the three factors.

As can be seen, the $P200_L$ and $P200_T$ loaded highly on factor 1, the $P300_A$ and $P200_A$ on factor 2, and the AH5-II and AH5-I on factor 3. The IT measure loaded highly positively on factor 1 and factor 2, and highly negatively on factor 3. The mean $P200_T$ of AEPs to the digit stimuli loaded negatively on factor 3. Table 9.10 shows the pattern of the sorted factor loadings. From these loading patterns, it was quite clear that factor 1 represented a speed factor reflecting an encoding process, which was specifically involved in the IT task and which had little to do with subjects' intelligence measured by the AH5 test (Saccuzzo *et al.* 1986).

Table 9.8
Correlation matrix of the eight measures

(n=35)

Measures	IT	$P200_L$	$P200_A$	$P200_T$	$P300_A$	$P200'_T$	AH5-I
IT							
$P200_L$	.424						
$P200_A$	.353	.022					
$P200_T$	.640	.671	.289				
$P300_A$	.510	.062	.590	.362			
$P200'_T$	.335	.070	.082	.087	.016		
AH5-I	-.240	.139	.229	.156	.167	-.422	
AH5-II	-.250	.028	-.047	.001	.118	-.137	.367

Note: $P200'_T$ was the mean $P200_T$ measure under the digit stimulus condition (see Table 9.6).

On the other hand, factor 3 appeared to represent a general speed factor, reflecting an encoding process which was required in a wider range of tasks. It was this general speed factor which might have contributed to subjects' intellectual ability (Saccuzzo *et al.* 1986), because on the one hand the two IQ measures loaded highly positively on this factor and, on the other hand, the $P200_T$ measure of AEPs to the digit stimuli and the IT measure loaded highly negatively on it. Therefore, factor 1 was named here as the specific speed factor of the encoding process in the visual IT task, or SSF; and factor 3 the general speed factor of encoding process for visual stimuli, or GSF.

Table 9.9
Factor loadings after varimax rotation

Measures	Factor 1	Factor 2	Factor 3
IT	.611	.496	-.469
$P200_L$	.923	-.102	.068
$P200_T$	.872	.300	.013
$P200_A$	.034	.874	.031
$P300_A$	.151	.876	.066
$P200'_T$	.119	.087	-.687
AH5-I	.117	.197	.842
AH5-II	.021	.008	.644
% variance	25	24	23

Table 9.10
Patterns of the sorted factor loadings

Measures	Factor 1	Factor 2	Factor 3
$P200_L$	.923	.000	.000
$P200_T$	.872	.300	.000
IT	.611	.496	-.469
$P300_A$	.000	.876	.000
$P200_A$	.000	.874	.000
AH5-I	.000	.000	.846
$P200'_T$	.000	.000	-.687
AH5-II	.000	.000	.644

Note: those factor loadings smaller than 0.300 were replaced with 0.000.

Factor 2 appeared to reflect the characteristics of the evaluation process, such as the confidence criterion for making a decision (Surwill, 1977). High scores on factor 2 might have indicated a high criterion of confidence as well as a long IT. Therefore, factor 2 was called the evaluation strategy factor, or ESF. The total explained variance (72%) was almost evenly distributed among the three factors (i.e. 25%, 24% and 23% for factor 1, 2 and 3, respectively).

The above findings agree with the idea that the reason for the IT-IQ correlation is that both measures are related to fundamental aspects of information processing (Anderson, 1986). In particular, they suggest that one of these fundamental aspects is at least partly the speed of information processing at its encoding stage (Todman & Gibb, 1985). However, the task-specific attribution of the IT task may be stronger than expected from earlier work, whereas the $P200_T$ parameter of AEPs to stimuli of a general cognitive task seems to be the AEP measure that clearly linked with both IQ and IT.

9.5. General discussion

9.5.1. P200 component and encoding process

In this experiment, we have seen not only that the correlations between the temporal measures of the P200 component and the inspection time were obtained once again, but also that there was a significant difference in amplitude of the P200 component under the conditions with and without IT-task loading. All of these results were in support of the view that the P200 component indexes the process of encoding, or transferring, sensory information from a sensory register into STM (Chapman *et al.* 1978), and they also provided evidence for the hypothesis that the inspection time is a measure of the input process (Vickers et at, 1972).

As has been said earlier, some may argue that the enhancement of the

P200 component in the IT-task loading trials could have been due to the strong preceding CNV activity, or might have been a differential preparation artifact, (Satterfield, 1965; Spong *et al.* 1965; Morrell & Morrell, 1966). If this was the case, it would be misleading to consider the significant difference found between P200 amplitudes under the conditions with and without the IT-task loading as valid evidence in favour of the above view. However, although it might well be the case that the CNV activity had affected the P200 amplitude to some extent, the overwhelming contribution to the enhancement of the P200 amplitude made by the IT-task loading condition should not be neglected.

Several points can be raised against the argument that the difference in amplitude of the P200 component to the IT-type stimulus under the two conditions with and without IT-task loading merely reflected a preparation artifact. For instance, if it was a preparation artifact, why was it that the N150 component recorded at the vertex was not significantly affected by the differential preparation (Fig. 9.1)? Also, there was a difference in CNV activity at the occiput between the trials with and without IT-task loading prior to the stimulus onset (Fig. 9.3), but no difference was found for the P200 amplitude recorded at the same position.

Evidence from the literature also indicates that the P200 component of AEPs elicited by target stimuli is larger in amplitude than that elicited by non-target stimuli while the CNV activities remained same for both stimulus conditions (Roth, 1973; Squires, K.C. *et al.* 1975). In one study, Wastell & Kleinman (1980) presented 8 letters (D, E, F, H, I, O, T and U) in a series of random sequences to their subjects, whose task was to detect by counting the number of the presentations of letter I in one condition and the number of the presentations of letter E in a second condition. These letters were presented at a constant rate of 3 per second. During the test, subjects' ERPs were recorded at the occiput as well as the vertex. It was found that there was no between-condition difference at either recording site for the AEP epoch before the occurrence of the P200 component, and the P200 amplitude at the vertex was larger for the target letters than for the non-target letters ($t=4.6$, $df=5$, $p<.01$). Apparently, the difference in amplitude of the P200 component could not be caused by subjects' different preparations to the target and non-target letters because they did not know in advance which letter was coming next. On the other hand, as indicated in Chapter 8, this finding suggested that if the P200 component does index the process of sensory information encoding, this process must be of dynamic origin (see Section 8.1.1).

The P200 component can also be affected by subjects' knowledge of time of onset of the stimulus. Schafer *et al.* (1981) studied the effects of subjects' knowledge of time of onset of the stimulus on the evoked cortical potentials. In order to manipulate the independent variable (knowledge of stimulus timing), two conditions were employed: a foreknowledge condition during which the evoking tone stimuli occurred coincident with every tenth, regularly occurring count (zero) on an electronic counter, thereby cuing subjects as to exact time of stimulus delivery; a no foreknowledge condition during which identical tones again occurred at the same rate of 1 every 10 second but without any temporal relation to the numbers displayed on the electronic counter so that subjects would not know when the evoking tones occurred. In both conditions, subjects were also asked to keep a running count of the number of fives which appeared on the electronic counter. They found that the knowledge of stimulus timing attenuated the P200 component of AEPs. The P200 amplitude was larger ($F(1,14)=15.90$, $p<.005$) and the P200 latency was longer (F(1,14)=28.69, $p<.001$) when the subjects did not have the knowledge of stimulus timing than when they did know. It seemed that subjects were encoding less information into STM if they knew exactly when the stimulus would come. Furthermore, using a period analysis of recorded EEG data the authors observed a significantly greater amount of EEG activity in the 'beta' band (13-25 cycles per second) during the foreknowledge condition than during the no foreknowledge condition (F(1,14)=5.55, $p<.05$), thus suggesting greater cortical arousal for subjects under the condition of foreknowledge. The fact that greater cortical arousal was seen together with a decreased rather than an increased P200 amplitude was contradictory to the argument that the enhancement in the amplitude of the P200 component was a solely differential preparation artifact.

Some studies even show that the P200 component increased in amplitude corresponding to those stimuli which subjects thought had high interest value. Homberg *et al.* (1984) presented their subjects with a series of up to 360 different visual stimuli, 150 msec in duration and subtending 10.5 degree of visual angle around a fixation point. The stimuli were easily identifiable pictures (black-and-white and coloured) of a wide variety of objects including geometrical figures, faces, animals, landscapes, etc. Stimuli were presented in random order. In each trial, a 200 msec warning tone delivered through headphones indicated that a visual stimulus would occur 2 seconds later. Subjects were instructed to give a verbal judgment of strength of interest in each stimulus, using an ordered 7-point category scale. The verbal response was delayed until the delivery of a second tone 1.5-2.2 second after the visual stimulus. The results of the study showed that the P200 amplitude, which was defined as the maximum positive amplitude in the range of 200-300 msec after the stimulus onset, was associated with the categories of the interest scale (F(6,30)=2.49, $p<.05$), The effect was mostly seen in the ERPs recorded from C_z and F_z. A larger P200 amplitude was linked to a high interest value for the stimulus. This finding not only indicated that the encoding process indexed by the P200 component is dynamic in general, but also implied that subjects' attitudes may affect the process of sensory information encoding in particular.

The idea that the encoding process indexed by the P200 component can be influenced by one's attitude is illustrated in a study by Thier *et al.* (1986). The study was carried out among a group of patients with depression and a group of normal people. Target and non-target stimuli with equal probability were presented to subjects. For the target stimuli, subjects were asked to react by pressing a button as soon as possible, and for the non-target stimuli, they were asked to withhold the action. It was found that the patient group reacted with larger P200 amplitudes in response to the non-target stimuli, and the normal group did the opposite (F(1,20)=11.9, $p<.01$). The finding was interpreted as a difference in response set: the normals being more inclined to activity and the patients to caution or retirement (Thier *et al.* 1986). Given that depressed persons have usually held negative attitudes towards positive actions in day-to-day life (Ullmann & Krasner, 1975; Snaith, 1981), this finding suggested that anti-action attitudes possessed by patients with depression might have interfered to some extend with the encoding of action-related sensory information, and as a result, the P200 component was reduced in amplitude among these patients.

Also, it is interesting to note that the P200 component of visual AEPs was found to be larger among a group of congenitally deaf adults in comparison with that of the normals. Neville *et al.* (1983) recorded visual evoked potentials from a group of 8 congenitally deaf adults and a group of normal people. They found that over the posterior scalp, including the vertex, the deaf subjects had a larger positive component, with a latency of about 230 msec for both peripheral and foveal stimuli, than did the normals ($p<.001$). From the point of view that the P200 component reflects the process of sensory information encoding, this finding simply suggested that as a compensation for their hearing loss, deaf people may have developed a more efficient visual encoding system, in comparison with the normals, to overtake the functions normally undertaken by auditory system. Under the same conditions, the encoding system of deaf people could have allowed more information to be encoded into STM through the visual modality, and thus the larger P200 amplitude resulted.

9.5.2. P300 component and evaluation process

It seems that on the one hand the P300 component was contingent on the completion of the evaluation, and on the other hand the amplitude of the P300 component might have reflected some characteristics of that process, such as the confidence criterion in decision making (Vickers & Smith, 1986). A post hoc analysis provided evidence supporting this view.

The analysis was based on the speculation that a high confidence criterion should lead to fewer errors being made during the IT task. Subjects who adopted a high confidence criterion and needed to encode more information to satisfy this demanding criterion should, as a result, have relatively long ITs when compared with those whose criterion was low (as we have seen above). Also, subjects with the high confidence criterion should have made fewer errors during the ERP recording session for the IT-task loading trials (70 in total) than those with the low criterion. If the P300 amplitude reflects the confidence criterion adopted, it might have varied in accord with the numbers of errors made by these subjects in the ERP recording session. That is, the larger the P300 amplitude was, the fewer would be the errors.

Two subgroups of subjects with the IT scores either greater than 40 msec or less than 30 msec were selected to see whether the above speculations were confirmed. Table 9.11 contains all the relevant data.

Table 9.11
Number of errors made in ERP session

IT scores shorter than 30 msec			
No. of subject	IT score	Errors	P300 amplitude
1	23	10	1.67
2	23	6	1.94
3	26	3	9.85
4	27	5	8.36
5	28	4	6.77
6	28	6	3.06
7	28	7	1.36
8	28	8	7.17
9	29	11	1.94
Mean	26.78	6.67	4.68
S.D.	2.33	2.65	3.33
IT scores longer than 40 msec			
No. of subject	IT score	Errors	P300 amplitude
1	41	2	5.28
2	43	5	2.22
3	44	3	5.69
4	44	5	6.94
5	45	2	2.78
6	48	5	8.33
7	49	2	6.11
8	59	3	13.19
9	68	5	6.67
Mean	49.00	3.56	6.36
S.D.	8.86	1.42	3.21

As can be seen, subjects in the long IT group did make fewer errors (3.56 in average) in the ERP recording session than did subjects in the short IT group (6.67 in average). The difference in number of errors made by the two groups was significant (Mann-Whitney: U(9,9)=11.00, p<.005 for one-tailed test). The correlation between the number of errors and the P300 amplitude was also significant in the predicted direction among the 18 subjects (r=-.47, n=18, p<.025). All these results thus suggested that the P300 amplitude had indeed reflected the criterion of confidence subjects adopted in their IT task performance for decision making.

9.5.3. IT-IQ relation and AEP measures

In the last chapter, a model for inspection time was described, which included three aspects of information processing, viz. the anticipation, encoding and evaluation. In this experiment, the process of anticipation did not appear to play an important role in IT estimation. This may be because of the use of relatively short warning interval (Morrison, 1982).

On the other hand, the encoding process appeared to have been broken down into two parts, one being the specific speed factor (SSF) and the other the general speed factor (GSF). It is the latter that was related to subjects' intelligence. This finding is in favour of the theoretical view that processing speed may be a general factor in individual differences in performance on complex intellectual solving tasks (Jensen, 1985; Anderson, 1986; Kirby & McConaghy, 1986). Saccuzzo *et al.* (1986) supplied similar evidence by a different approach. In their study, a battery of tachistoscopic, auditory, reaction time and microcomputer-generated measures of speed of information processing, including inspection time, were administered to 96 college students aged between 18 and 22 years. Scores on some IQ subtests such as the Vocabulary and Block Design of WAIS-R were also observed. By hierarchical factor analysis, results revealed a general processing speed factor in addition to task-specific sources of variability. And, moreover, the IT tasks loaded on the same second-order factor as did the intelligence measures.

In order to avoid any misunderstanding that might result from the above discussion, it may be better to note explicitly here that what has been said above does not exclude the possibility that the SSF may be associated with some subtests of intelligence, which examine specific abilities; for example, perceptual-spatial ability. In fact, some studies have shown evidence supporting this view (Mackenzie & Bingham, 1985). Nettelbeck *et al.* (1986a) observed that the results they obtained from two independent experiments of the IT-IQ relation appeared to be inconsistent. In the first experiment, they found that the visual IT was related to those intelligence tests that usually have a high factor loading on a general intelligence, (r=-.41, p<.05, one-tailed), but it was not associated with the primary abilities of perceptual speed (r=-.15, n.s.), as conventionally defined by checking sameness or difference between groups of letters and numbers (Perceptual Speed and Accuracy, a subtest of the Comprehensive Ability Battery, see Hakstian & Cattell, 1982). Neither was IT related to speed of closure (r=.07, n.s.), defined in terms of the identification of words where letters have been both scrambled and degraded (Speed of Closure, a subtest of the Comprehensive Ability Battery). They indicated that these results were consistent with the view that the inspection time is associated with some general intellectual capacity, rather than with specific abilities. In their second experiment, WAIS-R was used to measure subjects' IQs. The profiles of IT correlations with WAIS-R subtests, however, suggested that the overall outcome was predominantly the consequence of association between IT and Performance IQ subtests (Table 9.12).

While those Performance IQ subtests strongly associated with the IT measure have been found to correlate quite strongly with a general intelligence factor, other subtests not significantly related to the IT measure have been found to have even higher loadings on the general intelligence factor (Blaha & Wallbrown, 1982). The results from Nettelbeck's second experiment seemed to indicate that inspection time was not most clearly related to subtests with the highest g-loadings. The authors then stated: "The pattern of correlations between IT and Performance IQ subtests in the second experiment suggests that IT-IQ covariation could be limited predominantly to a general perceptual-spatial capacity, but the outcome from the first experiment was certainly not consistent with this."

Table 9.12
Intercorrelations among two measures of IT and WAIS-R IQ

Measures	(n=43) IT measure A	(n=40) IT measure B
Full Scale IQ	-.40**	-.46**
Verbal IQ	-.34*	-.38**
Performance IQ	-.49**	-.55**
Information	-.08	-.12
Digit Span	-.19	-.28*
Vocabulary	-.12	-.21
Arithmetic	-.14	-.27*
Comprehension	-.11	-.16
Similarity	-.06	-.06
Picture Completion	-.13	-.15
Picture Arrangement	-.30*	-.45**
Block Design	-.33*	-.49**
Object Assembly	-.29*	-.38**
Digit Symbol	-.41**	-.37**

Note: * p<.05; ** p<.01, one-tailed. Data from Nettelbeck *et al.* 1986a.

In the present experiment, we saw that the speed factor at the stage of encoding could be divided into two parts, one being the SSF and the other the

GSF. Both contribute to the IT measure. Nettelbeck's results mentioned above may not be inconsistent if they are interpreted using these two speed factors. It might be that, depending on which of the IQ tests is used, the IT-IQ covariation may manifest itself in favour of the predominance of either a general intelligence factor or a general perceptual-spatial capacity (Saccuzzo *et al.* 1986). It may be expected that for the IQ tests which are associated with the SSF, the predominance of a general perceptual-spatial capacity may result. Conversely, the predominance of a general intelligence factor may occur if the IQ tests used have a strong link with the GSF.

It was quite clear from this experiment that the evaluation process was important in IT estimation. The importance of the evaluation was seen through the evaluation strategy factor (ESF) revealed by the PCA, where the IT measures loaded highly as well as the P300 amplitude. Evidence from the post hoc analysis was consistent with the hypothesis that the confidence criterion adopted by subjects in dealing with the IT task may have been one of the characteristics of the evaluation process, and a stringent criterion of confidence may have characterized those subjects who had showed long ITs. As one may expect, this aspect of what IT measure measures was found to have had little relation to subjects' intellectual ability.

CHAPTER 10

CONCLUSION

In the introduction chapter, a general goal was set up for this study, that is, to search for some evidence that might deepen our understanding of the nature of the widely reported IT–IQ relationship. As far as this purpose is concerned, the present study appears to have been quite successful.

10.1. The P200 hypothesis

It has been shown that the P200 component decreases in amplitude when an external stimulus is absent or when a subject is asleep (Barlow *et al.* 1965; Klinke *et al.* 1968; Fruhstorfer & Bergstorm, 1969; Picton *et al.* 1974). This characteristic of the P200 component implies that the active state of the encoding mechanism of information processing may be responsible for generating the P200 component. In other words, the P200 component of AEPs recorded at vertex may be the cortical indicator of the process of encoding, or transferring, sensory information from a sensory register into STM (Chapman *et al.* 1978).

In the present study, subjects' ERPs were recorded at the vertex and the results obtained were consistent with the above hypothesis of the P200 component. In Exp. 1, it was found that the P200 components elicited by task stimuli with different exposure durations were identical. In Exp. 2, an individually characteristic P200 was produced under remarkably different conditions, some of which were the same for every subject. The combined results of the two experiments indicated that a temporal measure ($P200_T$) of the P200 component correlated positively and significantly with the measure of inspection time. Exp. 3 confirmed the IT-$P200_T$ association. Also, it found that the latency of the P200 component correlated with the inspection time in the same way as did the $P200_T$ measure. Taking into account the question of the power coefficient, Exp. 6 provided further evidence which not only confirmed the P200 hypothesis and the IT-P200 association observed in the previous experiments, but also indicated that the process of anticipation was not responsible for the IT-P200 relation when the IT task had a 500 msec warning period. All of these results were consistent with the P200 hypothesis, i.e. the P200 component reflects the process of encoding. Moreover, they indicated that the temporal measures of the P200 component index the speed of the encoding of information processing for visual stimuli. It seemed that the P200 component of AEPs recorded at occiput did not satisfy the P200 hypothesis.

The above interpretation of the role of the P200 component of AEPs recorded at the vertex to visual stimuli may also be applied to that of the P200 component of AEPs to auditory stimuli. Picton and Hillyard (1974) asked subjects to detect and count the number of omitted stimuli occurring irregularly every 5-30 seconds in a train of clicks. The clicks were presented at a rate of one per second. A complex of waves with a large positive component at about 400 msec was recorded following the absent stimulus, but the well-known potential (i.e. the complex of the N150-P200) was not observed. They suggested that the N150-P200 complex may represent the activation of neural assemblies involved with analysis of incoming auditory information.

Another view about the P200 component that is closely related to the P200 hypothesis is that the process of encoding, as indexed by the P200, is likely to be dynamic in relation to other stages of information processing. It means that the process of evaluating encoded information may begin while information is being encoded, and the amount of information being encoded depends upon the progress of the process of stimulus evaluation. For instance, the more meaningful the encoded information was, the more information would be taken in (Shevrin & Fritzler, 1968). The amplitude of the P200 component of AEPs to task relevant stimuli was larger than to task irrelevant stimuli (Sheatz & Chapman, 1969; Squire K.L. *et al.* 1975; Wastell & Kleinman, 1980). The P200 amplitude was smaller when subjects had some foreknowledge of the stimulus than when they did not (Schafer *et al.* 1981). Subjects' attitude could affect the amplitude of the P200 component (Homberg *et al.* 1984; Thier *et al.* 1986).

A paradigm similar to that used in studies of semantic priming may be employed to further investigate the dynamic origin of the P200 component (Kutas & Hillyard, 1980, 1984; Bentin *et al.* 1985). In those studies, subjects are usually presented with sentences which have the ending word aberrant physically and/or semantically. Subjects' ERPs to the ending word are recorded and analysed. By replacing the aberrant ending word of a sentence with a word which makes the sentence either negative or positive psychologically, it may be expected that sentences with negative ending words will be associated with a P200 component that is decreased in amplitude, and sentences with positive ending words will show the opposite. Experiments of this kind will provide us with evidence that can be very useful with respect to our understanding of the nature of the P200 component of AEPs recorded at the vertex.

The idea that the process of encoding is of dynamic origin has been expressed in concrete terms in Chapter 7, i.e. the 'second look hypothesis'. This hypothesis was proposed in order to explain some results obtained in

Exp. 5. It states: the overall process of encoding and evaluation might work in a periodic mode, i.e. 'encoding - evaluation - encoding - evaluation - ...'. The well-known vertex P200 wave indicates the beginning of the overall process, or reflects the first encoding phase. The overall process is terminated by the occurrence of the P300 component, which indicates that a mental decision has been achieved by a subject. In situations in which the subject needs to encode or sample more times because of the complexity of a task or for other reasons, more positive peaks will occur before the P300, in correspondence to these phases of encoding (Squires, N.K. *et al.* 1975; Adam & Collins, 1978; Hillyard, 1984; Stuss *et al.* 1984). When this happens, variation in the peak that occurs immediately before the P300 may be likely to be related to variation of the overall process (see Section 7.4.2). The IT-P200 relation obtained in the present study may have been a special case of this 'second look' hypothesis, in which the first phase of encoding may enable subjects to take up enough information for them to make a mental decision. From this point of view, the 'second look' hypothesis is just an expended version of the P200 hypothesis. Needless to say, far more research needs to be done before we can draw any conclusion with confidence.

10.2. The IT hypothesis

The view that the inspection time indexes the rate of sampling of sensory input in the initial stages of information processing (Vickers *et al.* 1972; Saccuzzo *et al.* 1979; Nettelbeck, 1982; Vickers & Smith, 1986) has been validated in the present study. It was found that the inspection time could be related in a meaningful way to the temporal measures of the P200 component of AEPs recorded at the vertex. It was seen consistently that a slow IT estimate was associated with a large value of the temporal measures (i.e.

$P200_T$ and $P200_L$) of the P200 component. This finding confirmed that the inspection time varies as a function of variation in the speed of encoding sensory information from a sensory register into STM; fast encoding was reflected by a quick development of the P200. The strength of this association is somewhere around 0.55 (a mean estimate based on the correlations obtained in Exp. 1 & 2, 3, and 6).

Moreover, evidence revealed in this study suggests that under some circumstances there exist at least three stages of information processing that contribute to the IT measure. These processes are the anticipation, encoding, and evaluation. In Exp. 4 and 5, it was seen that the degree of subjects' anticipation, as indexed by the amplitude of the CNV component, correlated significantly with the IT measure in the way that a strong anticipation was associated with a poor task performance. In both experiments, a 1800 msec warning period from the onset of a cue signal to that of a task stimulus was in use. When the warning period was fixed at 500 msec in Exp. 6, the IT-CNV relation was no longer observed. Instead, Exp. 6 confirmed the IT-P200 association seen in Exp. 1, 2 and 3, in which the 500 msec warning period was also in use. Obviously, the IT-P200 correlation observed under the condition of the 500 msec warning period indicated the importance of the process of encoding in subjects' performance on the IT task.

It seems necessary to carry out some studies that examine the relation between warning period and subjects' performance on the IT task. The results in Exp. 4, 5 and 6 of this study suggested that subjects' performance might vary with the warning period. If so, we should examine in more detail how the IT measure varies with the warning period and whether there are differences among subjects in an 'optimal' warning period for IT performance (Morrison, 1982).

For the process of evaluation, it was seen through all six experiments that the latency of the P300 component, presumably reflecting the completion of stimulus evaluation, correlated positively, but not significantly, with the IT measure. However, it was found in Exp. 6 that the P300 amplitude, which reflects the level of subjects' confidence on their responses, could be related in a meaningful way to the inspection time. A high confidence criterion was associated with a long IT estimate. As may be expected, this implied that subjects who adopted the high confidence criterion needed to encode more information in order to satisfy the demanding criterion. The claim that the evaluation of information processing plays a part in the IT task is also supported by the results from a post hoc analysis in Exp. 6. This analysis disclosed that subjects with long IT estimates and a high confidence criterion, as indexed by the P300 amplitude, made fewer errors than did those whose IT estimates were short and whose confidence criterion was low. That a stringent criterion of confidence is associated with a slow IT estimate was not merely a logical inference, but an empirical finding as well. Since the confidence criterion for decision making is one of the characteristics of evaluation, these findings indicated that the process of evaluation contributes at least to some extent to the IT measure (Vickers & Smith, 1986).

10.3. The nature of the IT–IQ relation

Results obtained in the early experiments (i.e. Exp. 1 & 2, and 3) of this study indicated that the process of encoding played a crucial part in the IT task and the slow speed of that process, as indexed by larger values of the temporal measures of the P200 component, correlated positively with subjects'

IT estimates. In the final experiment of this study, results suggested that the speed of the process of encoding in the IT task situation may consist of two parts, one being a general speed factor (GSF) and the other a specific speed factor (SSF). The GSF may underlie all processes requiring the encoding of sensory information, whereas the SSF may involve specifically to the visual IT task. It was found in the present study that it was the former which was related to subjects' intellectual ability as measured by intelligence tests (Saccuzzo *et al.* 1986). The $P200_T$ measure of AEPs to digit stimuli of a number-discrimination task was seen to be associated to both IT and IQ scores. The relationships between the three measures (i.e. the P200 component, inspection time and intelligence) were in the expected direction according to the results reported by other authors (Brand & Deary, 1982; Hendrickson, 1973; Anderson, 1986). A high IQ score appeared to be associated with a fast GSF and with a short IT estimate. The short IT estimate seemed to be associated with both fast GSF and fast SSF (see Section 9.4.6). Therefore, in the sense that the GSF of the encoding process is one member of the family of speed of information processing, this finding agrees with the idea that intelligence is partly a. matter of 'mental speed' (Eysenck, 1982; Mackintosh, 1986).

Based on these findings, it appears that the nature of the IT-IQ relation, so far widely reported, can be understood in terms of their relationships with the speed of the process of encoding information from a sensory register into STM. It seems that a high speed of the GSF of that process contributes to some extent to a high intellectual ability as well as a fast inspection time. Therefore, variation in speed of the GSF among individuals may be responsible for the IT-IQ relation, in which the IT measure and IQ scores correlate negatively.

Also, these findings seem to have offered some useful clues in explaining why so far studies have only reported negligible correlations between IT and other supposed measures of mental speed such as reaction time (Vernon, 1981, 1983; Smith & Stanley, 1983; also see Exp. 6). The reason may lie in the fact that the inspection time indexes mainly the speed of encoding from a sensory register to STM, which may be different from other speed factors of information processing. If it is the case, then the IT measure does not have to fit neatly into models accounting for the IQ-RT relation (Vernon, 1986).

Overall, the present study can be viewed as a successful exploratory study. It was intended to investigate the three variables (viz. evoked potentials, inspection time and intelligence) at the same time. Results obtained in this study and their interpretations discussed in this thesis have added new ideas into the issues of the IT-IQ debate and to our understanding of the nature of the widely-reported IT-IQ association. The study, therefore, has made a worthwhile contribution to the IT-IQ investigation. What is more important is that it has generated some hypotheses for further research.

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II. Appendix A

Data of AEP measures across all trials
scored by two judges

	(1024 msec epoch)					
Parameters	$P200_L$		$P200_A$		$P200_T$	
Judges	A	B	A	B	A	B
(Session 1)						
Subjects						
1	42.8	42.6	18.5	18.5	7.4	7.6
2	39.8	39.7	34.7	35.0	10.5	11.1
3	40.4	40.1	31.8	31.8	7.5	7.3
4	41.0	42.0	10.5	11.5	11.5	13.2
5	39.9	39.8	20.5	20.5	9.0	9.7
6	36.6	36.3	16.5	16.2	5.0	5.5
7	39.2	39.1	36.7	37.2	10.2	11.5
8	38.7	39.3	35.3	28.8	16.5	16.2
(Session 2)						
Subjects						
1	42.6	42.6	16.7	16.5	6.4	6.5
2	40.0	39.9	34.2	34.5	11.2	11.0
3	40.2	40.4	31.2	31.2	6.6	6.5
4	41.0	41.5	9.8	10.0	11.5	11.5
5	40.8	41.0	18.2	18.2	9.9	10.5
6	37.2	37.2	14.4	14.8	5.5	5.5
7	40.4	40.3	37.2	36.4	12.4	12.4
8	39.5	39.6	34.0	34.2	16.5	16.7

Note: units were arbitrary.

Appendix B

Data of Experiment 1:

Subj.	Age	IT score	St. exposure duration		
			IT+	IT	IT-
1	22	27	47.25	27	6.75
2	23	23	40.25	23	5.75
3	25	19	33.25	19	4.75
4	30	52	91.00	52	13.00
5	21	28	49.00	28	7.00
6	24	18	31.50	18	4.50
7	27	28	49.00	28	7.00
8	21	78	136.50	78	19.50

P200 component (whole epoch)

Latency				Amplitude				P200_T			
IT+	IT	IT-	mean	IT+	IT	IT-	mean	IT+	IT	IT-	mean
211.5	210.5	219.0	213.7	2.9	2.9	2.6	2.8	30.1	31.6	33.8	31.8
200.0	207.5	192.5	200.0	5.7	6.1	5.3	5.7	53.6	64.3	43.9	53.9
205.0	204.5	197.5	202.3	5.8	4.9	4.8	5.7	32.1	37.2	29.5	32.9
215.0	200.0	215.0	210.0	1.8	1.5	2.5	1.9	69.4	50.8	65.0	61.7
222.5	197.5	191.5	203.8	2.3	2.8	4.0	3.0	47.5	59.0	42.5	49.7
192.5	177.5	187.5	185.8	1.5	2.8	2.9	2.4	29.5	25.0	28.0	27.5
210.0	200.0	195.5	201.8	5.8	5.3	7.1	6.9	68.5	58.4	55.2	60.5
195.0	203.0	194.0	197.5	7.0	4.5	5.3	5.6	86.0	74.5	87.5	82.7

P300 component

Latency				Amplitude		
IT+	IT	IT-	mean	IT+	IT	IT-
386.0	380.5	389.5	385.3	3.42	4.17	3.58
312.5	319.5	307.5	313.2	9.87	7.33	5.15
266.0	278.0	280.5	274.8	8.43	9.50	9.67
366.0	367.5	375.5	363.7	4.00	1.67	2.42
312.5	327.0	314.4	318.0	3.92	1.50	2.37
286.5	280.0	279.5	282.0	3.92	1.95	2.50
350.0	335.0	375.0	353.3	4.83	2.82	2.25
350.0	339.5	344.5	344.7	3.67	1.65	-1.33

(Units for following data were arbitrary.)

P200 component (window analysis)

Amplitude		P200_T	
All-trials	IT-trials	All-trials	IT-trials
21.24	20.25	7.59	6.75
23.75	25.00	8.30	8.80
29.35	28.00	6.43	7.00
12.58	12.25	12.84	12.25
17.17	16.25	9.42	10.75
13.33	15.00	5.32	4.65
22.59	20.00	9.40	8.70
19.00	18.50	12.20	12.00

Appendix B (continued)

Data of Experiment 2:

Subj.	Age	IT score	P300 component						
			Latency				Amplitude		
			Non	IT	Mask	mean	Non	IT	mask
1	21	38	80.5	80.5	79.0	80.0	28.5	21.1	17.0
2	29	37	63.1	63.1	64.2	63.5	28.0	12.8	21.0
3	22	27	76.1	77.2	68.5	73.9	30.1	45.0	31.5
4	24	17	53.0	45.8	46.1	48.3	10.5	7.6	8.9
5	24	37	58.8	56.5	60.0	58.4	19.5	20.0	19.4
6	20	34	72.0	69.0	67.0	69.3	63.5	43.0	36.1
7	23	17	74.5	71.0	71.5	72.3	88.2	70.1	64.2
8	21	18	58.2	67.5	57.0	60.9	61.5	51.2	52.0

P200 component (whole epoch)

Latency				Amplitude				$P200_T$			
Non	IT	Mask	mean	Non	IT	Mask	mean	Non	IT	Mask	mean
42.6	45.0	44.8	44.1	17.5	26.5	23.0	22.3	6.2	8.2	12.1	8.8
45.0	43.9	42.1	43.7	25.5	20.0	17.0	20.8	11.8	12.3	11.5	11.8
46.0	44.5	43.2	44.6	20.5	15.0	19.0	18.2	13.0	11.2	10.8	11.7
36.0	37.0	36.7	36.6	21.0	16.0	14.0	17.0	5.0	4.9	3.9	4.7
36.4	35.5	34.4	35.4	20.5	15.0	12.0	15.8	8.8	6.7	4.5	6.6
43.0	41.0	40.0	41.3	45.0	41.5	39.0	41.8	15.0	14.0	10.3	13.1
44.9	44.9	44.9	44.9	26.0	26.0	26.0	26.0	7.8	7.8	7.2	7.6
35.9	39.0	35.8	36.9	3.5	6.0	12.9	7.5	3.2	6.2	6.2	5.2

P200 component (window analysis)

Amplitude			$P200_T$			
Non	IT	Mask	Non	IT	Mask	mean
17.0	23.0	23.0	6.0	7.1	7.1	6.7
21.0	18.5	16.0	9.5	12.2	10.5	10.7
14.0	14.5	15.0	11.7	10.4	9.0	10.4
25.0	27.0	23.0	5.2	7.0	4.5	5.6
18.0	10.5	11.0	7.5	5.2	4.0	5.6
28.0	26.5	21.0	12.1	11.0	11.5	11.5
34.0	34.0	34.0	9.0	9.0	9.0	9.0
4.2	5.0	5.8	3.2	2.6	3.4	3.1

Appendix B (continued)

<u>The combined data from Experiments 1 and 2</u>:

Subj.	IT score	Whole epoch			75-275ms window	
		$P200_T$	$P200_A$	$P300_L$	$P200_T$	$P200_A$
1	27	6.3	17.4	76.1	6.75	20.25
2	23	12.8	36.6	63.9	8.80	25.00
3	19	13.8	29.4	55.6	7.00	28.00
4	52	10.2	10.7	73.6	12.25	12.25
5	28	11.8	16.8	65.4	10.75	16.25
6	18	5.0	16.8	56.0	4.65	15.00
7	28	11.6	31.8	67.0	8.70	20.00
8	78	14.8	27.0	67.9	12.00	18.50
9	38	8.2	26.5	80.5	7.10	23.00
10	37	12.3	20.0	63.1	12.20	18.50
11	27	11.2	15.0	77.2	10.40	14.50
12	17	4.9	16.0	45.8	7.00	27.00
13	37	6.7	15.0	56.5	5.20	10.50
14	34	14.0	41.5	69.0	11.00	26.50
15	17	7.8	26.0	71.0	9.00	34.00
16	18	6.2	6.0	67.5	2.60	5.00

<u>Data of Experiment 3</u>:

Sub.	IT	Age	$P200_L$	$P300_L$	$P200_T$	$P200_A$	$(N150\text{-}P200)_A$
1	24.0	38.0	37.9	72.0	9.3	14.0	25.0
2	18.0	47.0	37.4	53.6	5.5	7.5	17.0
3	20.0	26.0	36.3	54.2	5.2	13.8	38.1
4	18.0	27.0	31.5	57.5	7.2	19.5	45.5
5	18.0	23.0	35.5	76.0	6.4	9.0	32.0
6	18.0	28.0	37.7	71.2	6.0	25.0	41.5
7	27.0	23.0	40.0	75.0	6.3	9.0	23.0
8	19.0	37.0	38.0	59.0	5.8	8.1	11.2
9	17.0	25.0	30.0	71.5	3.8	5.5	22.0
10	35.0	23.0	37.5	60.0	10.2	19.0	44.0
11	41.0	33.0	42.5	76.5	6.3	4.5	25.0
12	26.0	24.0	40.9	61.5	7.1	10.9	25.0
13	19.0	34.0	41.0	71.0	6.4	17.1	32.6
14	24.0	28.0	32.5	54.6	7.0	10.5	38.9
15	29.0	15.0	34.5	70.0	8.6	18.4	39.5
16	29.0	19.0	34.5	76.5	5.0	13.6	26.0

Appendix B (continued)

Data of Experiment 4:

Sub.	Gap IT	RAPM	Age	P200$_L$	P200$_T$	P300$_L$	CNV
1	24	32	21	40.5	6.0	76.1	21.1
2	13	23	20	40.9	7.8	57.5	23.8
3	24	20	20	39.0	9.0	68.8	20.3
4	19	24	20	38.5	9.0	63.0	23.7
5	3	26	19	39.5	6.7	76.0	18.5
6	24	29	24	40.0	10.0	59.9	18.0
7	46	21	20	40.0	8.5	76.0	24.3
8	14		20	32.2	5.6	58.9	21.1
9	19	22	20	41.0	6.6	70.0	21.1
10	23		24	33.7	4.0	75.4	21.7
11	13	25	21	38.5	6.8	73.0	20.2
12	18	27	18	46.1	9.5	70.0	20.5
13	30	26	19	41.1	5.1	72.5	24.0
14	24	23	19	42.3	8.0	77.5	19.6
15	29	22	19	43.5	10.2	70.0	20.9
16	12	24	22	41.0	10.1	78.0	21.9
17	29	27	19	30.5	2.6	59.0	23.6

Data of Experiment 5:

Sub.	Age	IT	P200$_L$	P300$_L$	CNV	P200$_L$'
1	16	40	43.8	80.0	23.40	43.8
2	16	23	32.0	72.1	21.50	50.0
3	17	20	38.2	71.5	20.60	38.2
4	17	21	43.9	68.3	21.90	43.9
5	16	19	46.3	67.2	22.30	46.3
6	16	34	32.5	80.5	21.80	57.5
7	16	19	45.0	72.2	21.00	45.0
8	15	29	47.6	53.9	23.80	47.6
9	15	26	45.2	64.0	22.80	45.7
10	15	24	34.1	64.0	20.40	51.5

Appendix B (continued)

Data of Experiment 6 (IT-type stimulus):

Sub.	Variables 1	2	3	4	5	6	7	8	9	10	11
01	34	313.1	270.9	17.25	32.0	12.4	5.7	55.7	20.64	32.0	13.8
02	31	223.8	193.4	19.15	32.0	1.0	10.4	71.3	22.48	32.0	6.2
03	33	458.4	347.1	17.19	35.2	-7.5	5.2	57.0	19.12	36.2	1.0
04	44	336.4	230.5	19.70	35.5	14.0	7.2	59.0	21.57	34.7	26.0
05	39	217.6	214.1	21.67	38.5	19.5	6.2	52.0	23.22	36.0	32.0
06	23	322.3	311.9	17.52	40.0	11.0	5.0	77.0	17.53	40.0	22.3
07	49	561.7	376.7	19.80	42.0	0.0	11.2	57.0	23.27	49.5	26.5
08	68	335.7	344.6	20.02	30.0	2.0	4.7	67.6	26.89	44.3	20.5
09	48	411.0	309.2	23.86	34.5	22.5	11.9	53.0	22.25	33.0	15.2
10	33	250.7	274.2	22.61	40.0	8.2	6.5	57.5	23.46	40.0	12.8
11	27	404.3	394.4	25.72	29.0	17.0	4.0	52.0	25.38	38.2	21.1
12	31	445.6	398.0	22.34	35.5	-3.0	3.0	56.3	21.06	37.3	2.0
13	28	282.8	299.3	16.80	34.5	-5.0	3.5	61.2	19.31	38.0	8.0
14	38	246.5	193.9	20.81	31.0	15.2	4.1	61.0	29.31	34.9	39.0
15	32	305.9	317.3	21.39	39.1	9.0	11.6	60.0	21.75	37.5	11.0
16	28	408.9	303.1	21.04	32.1	8.8	3.8	56.0	25.08	34.8	17.8
17	33	329.8	270.6	18.57	33.8	7.0	4.7	53.8	15.96	46.8	6.0
18	23	245.2	233.5	18.55	35.0	-2.5	6.0	50.9	21.95	35.0	11.2
19	28	507.7	430.6	20.14	33.5	12.0	10.1	72.8	21.49	31.0	16.0
20	34	556.6	254.3	22.72	40.0	17.0	7.5	73.0	18.38	39.2	5.0
21	33	421.8	337.5	20.85	30.0	20.0	16.5	44.5	19.25	31.5	26.0
22	36	493.1	478.3	18.81	39.0	6.0	5.0	68.5	19.49	46.5	17.0
23	43	274.8	216.4	23.23	39.0	22.5	7.0	64.3	22.51	39.0	22.0
24	41	411.2	364.1	20.77	35.8	9.5	6.2	63.0	20.77	36.8	17.0
25	30	365.7	348.5	18.56	34.0	4.0	5.9	62.0	21.77	33.0	18.2
26	31	229.1	214.6	19.22	37.1	8.0	8.2	51.0	21.20	35.2	12.0
27	36	343.8	334.1	21.63	30.0	25.8	5.4	54.9	22.82	32.0	33.0
28	26	251.6	202.7	19.82	34.1	7.9	6.0	54.6	22.57	32.2	20.0
29	35	217.4	206.3	18.84	31.5	9.3	6.3	51.0	21.56	30.0	28.3
30	29	358.9	356.7	22.85	43.8	14.3	14.9	56.0	21.74	33.1	21.3
31	28	234.9	216.7								
32	43	319.3	253.0								
33	36	202.9	192.6								
34	32	239.4	206.2	19.42	35.9	3.5	8.6	61.5	23.19	34.6	15.0
35	33	430.7	227.2	18.03	32.0	-1.0	6.0	54.8	18.51	31.5	10.5
36	29	243.9	206.3	22.60	31.6	25.0	6.8	51.3	21.06	32.9	20.0
37	44	505.3	478.5	23.77	45.1	25.0	16.5	53.2	23.85	43.2	17.0
38	59	401.4	280.4	20.34	35.1	30.0	7.0	56.0	20.71	45.9	33.8
39	39	203.2	219.9	20.08	37.8	10.9	9.0	56.7	19.99	35.1	12.5
40	45	333.3	305.5	21.28	39.2	6.2	7.0	67.8	16.96	32.0	13.8

Note: Variables were: 1) IT; 2) RT-Load; 3) RT-Free; 4) CNV-Free; 5) P200_L-Free; 6) P200_A-Free; 7) P200_T-Free; 8) P300_L-Free; 9) CNV-Load; 10) P200_L-Load; 11) P200_A-Load. Missing values were left blank.

Data of Experiment 6 (IT-type stimulus):

Sub.	Variables 12	13	14	15	16	17	18
01	5.7	60.0	19	11	30	1.0	10.0
02	4.3	68.0	9	18	27	-4.0	9.5
03	6.3	60.0	14	17	31	-3.5	12.0
04	6.6	58.0	13	17	30	7.0	20.5
05	6.2	57.2	13	18	31	22.5	23.0
06	5.0	70.0	19	24	43	-6.5	6.0
07	17.5	56.9	21	23	44	-1.0	22.0
08	16.9	67.6	8	19	27	22.0	44.0
09	5.4	55.0	13	19	32	31.0	30.0
10	6.5	54.0	23	22	45	14.0	19.5
11	5.9	52.9	17	17	34	10.0	30.1
12	4.6	54.5	17	24	41	14.0	10.0
13	6.5	65.2	17	27	44	-5.5	4.9
14	6.3	61.0	17	19	36	-5.0	30.0
15	9.8	58.0	11	14	25	6.0	8.5
16	6.3	67.7	17	22	39	10.0	24.0
17	12.3	53.8	14	16	30	3.7	7.0
18	6.0	61.2	17	23	40	-8.0	10.5
19	6.2	80.0	14	25	39	1.0	11.0
20	4.5	58.9	12	26	38	17.0	20.0
21	16.5	45.0	20	25	45	30.0	32.0
22	12.6	60.0	22	21	43	10.0	10.0
23	8.2	57.0	15	17	32	-6.0	8.0
24	8.2	66.5	14	22	36	8.0	19.0
25	5.0	62.0	16	14	30	-3.0	15.0
26	5.6	65.1	12	17	29	7.0	16.5
27	6.0	54.9	13	20	33	15.5	22.5
28	3.6	65.0	19	26	45	2.1	35.5
29	6.0	73.0	23	21	44	-1.9	36.1
30	5.4	55.1				16.0	25.8
31			21	27	48		
32			23	15	38		
33			13	16	29		
34	6.7	64.5	21	24	45	-8.5	31.0
35	4.2	58.0	17	20	37	-7.5	13.0
36	6.8	69.0				7.0	7.0
37	15.0	58.0	20	22	42	27.0	25.0
38	16.7	78.5	18	17	35	25.0	47.5
39	5.0	56.8	10	16	26	0.0	11.0
40	9.2	60.0	14	18	32	2.0	10.0

Note: Variables were: 12) P200$_T$-Load; 13) P300$_L$-Load; 14) AH5-I; 15) AH5-II; 16) AH5-Total; 17) P300$_A$-Free; 18) P300$_A$-Load. Missing values were left blank.

Appendix B (continued)

Data of Experiment 6 (digit stimulus):

Sub.	Variables											
	1	2	3	4	5	6	7	8	9	10	11	12
01	34	20.44	31.0	5.0	50.0	20.87	30.0	5.2	50.0	19	11	30
02	31	20.56	35.8	5.4	52.5	24.43	33.5	7.0	53.0	9	18	27
03	33	22.07	29.5	4.0	58.8	21.06	30.0	3.9	60.0	14	17	31
04	44	24.65	33.5	6.9	59.0	26.40	32.5	6.2	54.0	13	17	30
05	39	19.07	34.0	6.5	51.2	18.06	34.0	7.2	51.2	13	18	31
06	23	27.16	35.2	5.9	72.9	22.30	37.8	7.1	71.5	19	24	43
07	49	23.34	32.8	6.8	64.0	22.23	34.1	8.2	61.2	21	23	44
08	68	21.92	30.0	5.2	71.5	22.67	41.0	14.2	81.5	8	19	27
09	48	26.53	39.2	12.7	50.0	26.55	40.1	12.7	53.8	13	19	32
10	33	21.31	31.5	3.3	50.0	22.18	33.1	3.6	51.5	23	22	45
11	27	25.36	33.5	8.2	57.0	26.30	34.7	7.9	56.1	17	17	34
12	31	20.93	31.9	3.0	53.2	22.96	33.0	4.0	52.2	17	24	41
13	28	17.42	35.5	5.2	54.5	21.37	35.5	5.2	64.5	17	27	44
14	38	22.98	31.2	6.3	67.3	20.18	31.2	6.3	71.5	17	19	36
15	32	23.65	30.0	5.1	67.1	21.27	29.1	6.5	60.9	11	14	25
16	28	22.97	30.0	2.6	63.7	22.93	31.5	4.5	58.3	17	22	39
17	33	22.56	34.9	5.0	54.5	21.34	33.6	7.5	54.5	14	16	30
18	23	23.82	34.0	7.0	60.0	24.06	32.6	6.0	64.0	17	23	40
19	28	18.70	31.9	8.2	61.5	19.02	34.0	10.7	61.5	14	25	39
20	34	23.20	36.8	6.5	56.1	23.53	36.0	6.8	58.2	12	26	38
21	33	19.17	28.0	5.5	43.2	17.44	41.5	5.2	41.5	20	25	45
22	36	20.02	42.0	9.0	66.2	20.32	36.2	4.9	52.5	22	21	43
23	43	20.98	36.7	6.2	53.0	21.60	34.1	10.1	70.0	15	17	32
24	41	15.49	34.0	5.5	59.1	16.05	34.0	5.2	59.1	14	22	36
25	30	22.26	33.5	6.6	60.5	20.69	31.0	5.3	58.0	16	14	30
26	31	22.06	30.0	5.0	48.6	24.67	30.0	4.5	50.0	12	17	29
27	36	22.54	29.0	4.0	51.5	22.86	29.0	5.1	50.0	13	20	33
28	26	22.24	43.0	4.2	57.6	21.04	41.5	3.0	56.2	19	26	45
29	35	19.29	25.4	4.0	50.0	21.77	26.0	5.0	58.4	23	21	44
30	29	21.28	29.0	4.7	54.2	21.34	27.0	4.5	54.2			
31	28									21	27	48
32	43									23	15	38
33	36									13	16	29
34	32	20.58	28.5	5.2	65.5	19.81	30.5	6.7	60.0	21	24	45
35	33	22.01	32.0	4.5	57.2	19.56	29.0	3.9	57.2	17	20	37
36	29	19.26	41.0	5.6	76.0	18.85	39.0	16.5	63.5			
37	44	23.25	31.1	3.6	52.0	22.48	31.8	3.5	46.2	20	22	42
38	59	20.34	28.9	4.0	55.5	20.71	29.5	4.5	57.0	18	17	35
39	39	18.86	34.0	8.3	59.2	19.15	34.0	7.1	55.0	10	16	26
40	45	18.84	36.0	7.3	60.0	19.74	33.2	6.1	56.8	14	18	32

Note: Variables were: 1) IT; 2) CNV-Free; 3) $P200_L$-Free; 4) $P200_T$-Free; 5) $P300_L$-Free; 6) CNV-Related; 7) $P200_L$-Related; 8) $P200_T$-Related; 9) $P300_L$-Related; 10) AH5-I; 11) AH5-II; 12) AH5-Total. Missing values were left blank.

Appendix B (continued)

Data of Experiment 6 (digit stimulus):

Sub.	Variables					
	13	14	15	16	17	18
01	27.2	32.5	30.2	34.0	313.1	270.9
02	15.0	16.5	20.5	19.0	223.8	193.4
03	17.0	30.0	15.4	25.0	458.4	347.1
04	43.8	33.0	39.0	22.0	336.4	230.5
05	43.3	46.1	41.2	38.5	217.6	214.1
06	42.5	38.5	41.0	30.0	322.3	311.9
07	40.1	36.8	33.0	31.5	561.7	376.7
08	22.5	37.0	24.0	27.0	335.7	344.6
09	47.0	52.0	46.0	49.0	411.0	309.2
10	20.5	26.2	21.0	35.5	250.7	274.2
11	40.5	45.5	50.5	45.0	404.3	394.4
12	23.0	39.0	25.5	42.0	445.6	398.0
13	30.0	31.5	41.0	35.0	282.8	299.3
14	34.2	12.5	30.0	-8.0	246.5	193.9
15	22.0	28.5	18.5	19.0	305.4	317.3
16	22.8	42.0	27.8	37.0	408.9	303.1
17	14.0	24.0	15.0	15.0	329.8	270.6
18	35.9	42.0	34.0	30.0	245.2	233.5
19	13.0	6.0	11.0	4.0	507.7	430.6
20	42.0	53.0	38.0	30.0	556.6	254.3
21	33.0	40.0	24.0	24.9	421.8	337.5
22	21.6	13.0	22.0	21.8	493.1	478.3
23	20.0	24.9	20.9	18.5	274.8	216.4
24	21.0	15.5	21.0	19.0	411.2	364.1
25	25.9	28.5	16.3	14.9	365.7	348.5
26	29.0	26.5	33.0	30.0	229.9	214.6
27	44.7	28.9	38.8	24.0	343.8	334.1
28	35.5	48.5	25.0	41.0	251.6	202.7
29	37.5	32.6	47.5	37.9	217.4	206.3
30	43.5	43.0	45.5	36.7	358.9	356.7
31					234.9	216.7
32					319.3	253.0
33					202.9	192.6
34	22.0	24.0	21.0	20.0	239.4	206.2
35	27.5	27.5	25.0	22.5	430.7	227.2
36	20.9	20.9	30.9	13.0	243.9	206.3
37	33.6	21.5	32.5	19.0	505.3	478.5
38	22.0	30.0	28.3	30.0	401.4	280.4
39	15.5	13.0	15.5	13.0	203.2	219.9
40	31.5	36.0	34.9	31.0	333.3	305.5

Note: Variables were: 13) P200$_A$-Free; 14) P300$_A$-Free; 15) P200$_A$-Related; 16) P300$_A$-related; 17) RT-Load; 18) RT-Free. Missing values were left blank.